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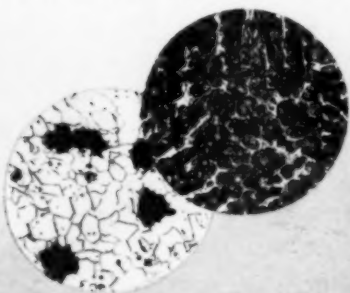
THE BRITISH JOURNAL OF METALS

Vol. 53 No. 316

FEBRUARY, 1956

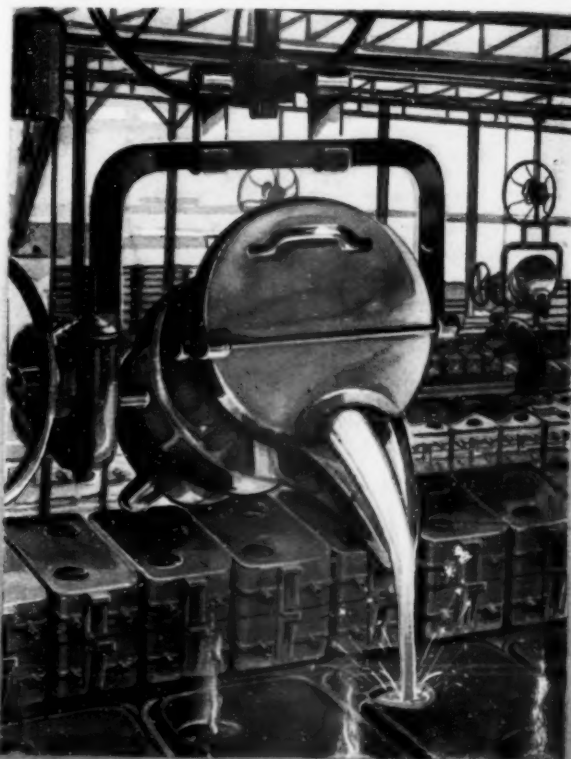
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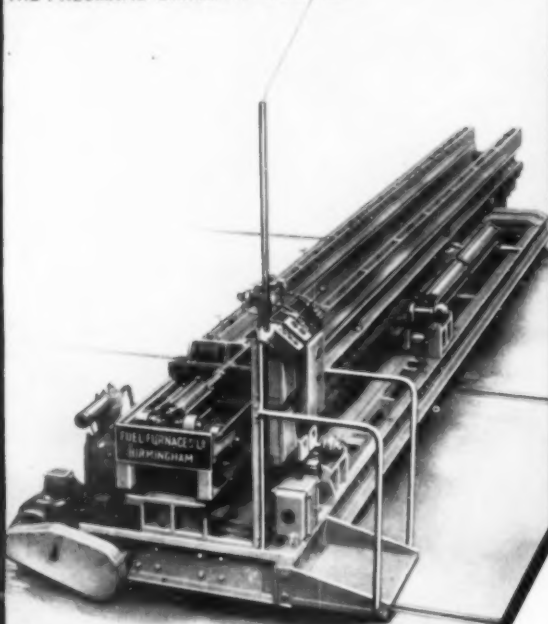
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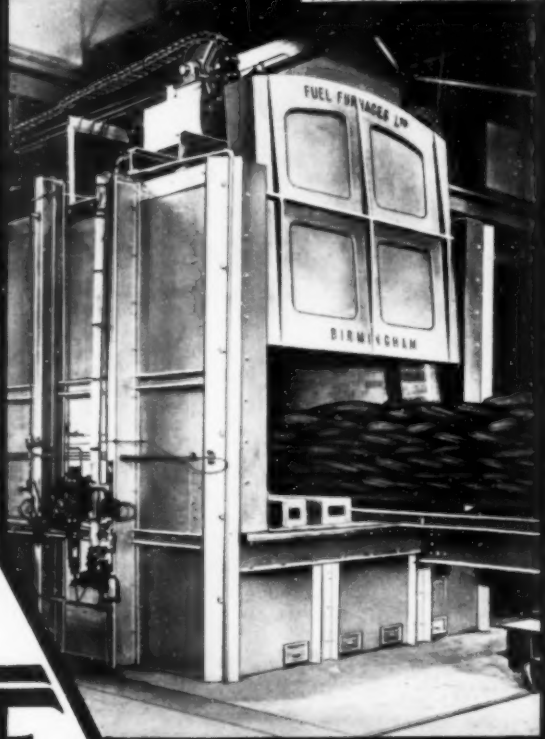
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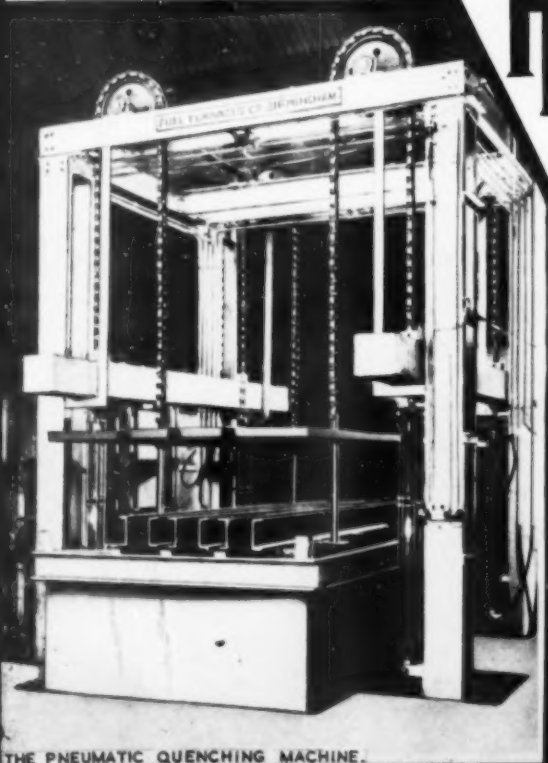
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METALLURGIA

THE BRITISH JOURNAL OF METALS
INCORPORATING THE METALLURGICAL ENGINEER

CONTENTS FOR FEBRUARY, 1956

Vol. 53

No. 316

PUBLISHED MONTHLY BY
The Kennedy Press, Ltd.,
31, King Street West,
Manchester, 3.
Telephone: BLAckfriars 2084

London Office:

50, Temple Chambers,
Temple Avenue, E.C.4.
FLEet Street 8914

CONTRIBUTIONS

Readers are invited to submit articles for publication in the editorial pages: photographs and/or drawings suitable for reproduction are especially welcome. Contributions are paid for at the usual rates. We accept no responsibility in connection with submitted manuscript. All editorial communications should be addressed to The Editor, "Metallurgia," 31, King Street West, Manchester, 3.

SUBSCRIPTIONS

Subscription Rates throughout the World—24/- per annum, Post free.

ADVERTISING

Communications and enquiries should be addressed to the Advertisement Manager at Manchester.

The articles in this Journal are indexed in THE INDUSTRIAL ARTS INDEX

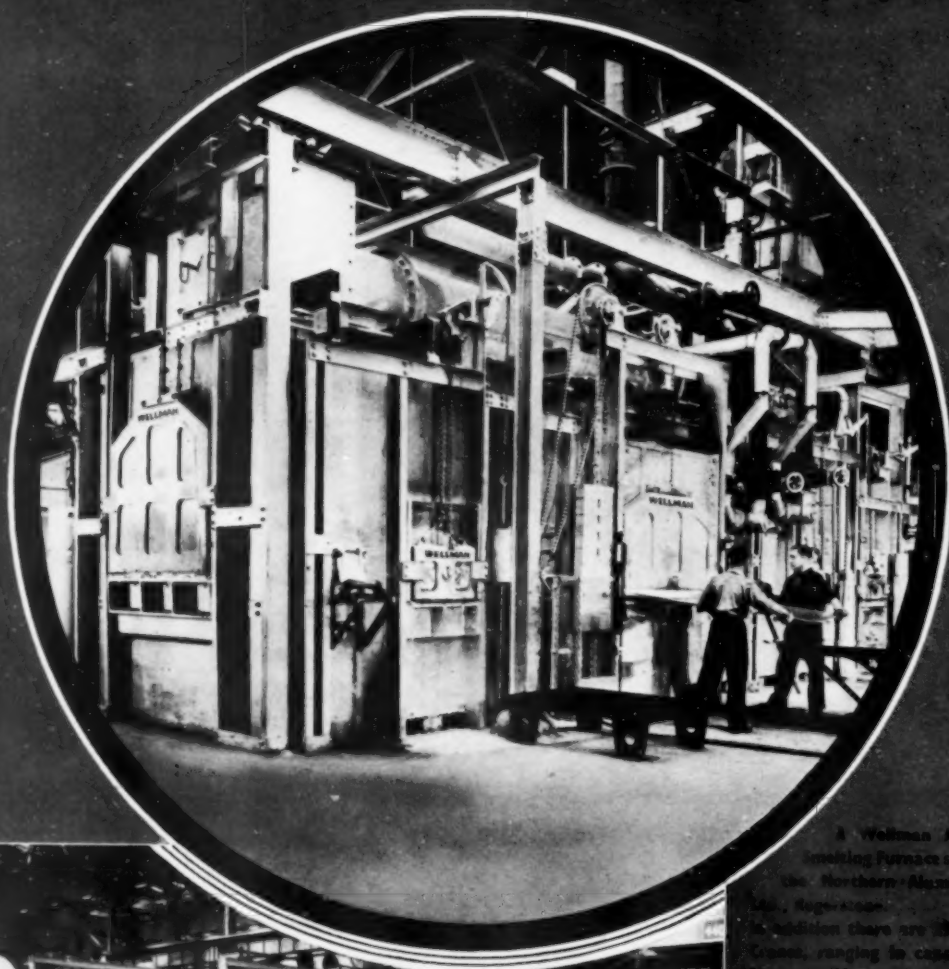
	Page
Foundry Conditions	55
Meeting Diary	56
Aluminium Finishes for Exterior Use. By J. C. Bailey and W. Evans	57-62
The Interaction of Static Stress and Corrosion with Aluminium Alloys. By F. A. Champion	63-68
Aluminium and its Alloys in 1955—Some Aspects of Research and Technical Progress Reported. By E. Elliott	69-79
Trends in the Welding of Aluminium Alloys. By P. T. Houldcroft	80-83
New Margam Blast Furnace is Europe's Biggest	83
Correspondence: The Solidification of Cast Iron	84-85
Revised British Standard	85
News and Announcements	86-88
Recent Developments	89-90

LABORATORY METHODS SUPPLEMENT

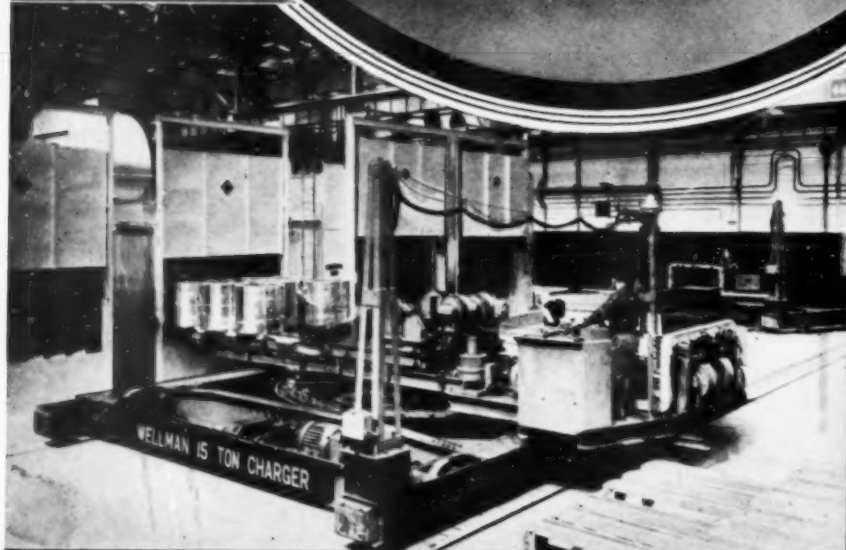
Liquid-Liquid Extraction Procedures in Inorganic Analysis—A Review of Practical Applications with Particular Reference to Metallurgical Analysis. By T. S. West	91-96
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METALLURGIA

THE BRITISH JOURNAL OF METALS

INCORPORATING THE "METALLURGICAL ENGINEER"

FEBRUARY, 1956

Vol. LIII. No. 316

Foundry Conditions

IN a period of full employment, the rewards available to the unskilled worker in many mass production factories are such that the advantages of serving an apprenticeship to a craft are not so obvious as they once were. On the other hand, the superior outlook for manual workers, as compared with the lower grade of office worker, probably influences some of the boys of average educational background to take up factory work where they would, before the war, have tended to seek a white collar job. At a time when certain industries have a surfeit of would-be apprentices, there is one—the foundry industry—which is hard put to obtain them in numbers sufficient to replace normal wastage of skilled men. This is almost certainly due, in some measure, to the working conditions in many foundries, which have been—and still are in some instances—far from ideal. Conditions have, however, improved considerably in the post war years, and further progress in this direction continues.

From 1st October, 1946, when the former Iron and Steel Board was instituted, until 31st December, 1953, the Ministry of Supply approved 269 applications for licences to carry out building and civil engineering work, primarily to improve working conditions in iron foundries, and to provide lavatories, washing facilities (including baths) and canteens. The total estimated expenditure on these schemes was over £1½ million. In addition, the Ministry of Supply approved schemes for new iron foundries, and extensions and repairs to existing foundries, involving a total expenditure (including the cost of plant and equipment) of £17½ millions. Of this, some £1½ million represents the cost of amenities and improvements in working conditions.

In 1947, there was published the Report of the Joint Advisory Committee on Conditions in Iron Foundries—more familiarly known, as the Garrett Report—in which a number of recommendations were made. As a result of one of these, H.M. Chief Inspector of Factories set up at the end of that year a Joint Standing Committee on Conditions in Iron Foundries, with the following terms of reference: "To keep under review conditions and developments in the iron foundry industry affecting the health, safety and welfare of the workers; to implement and continue the work of the Joint Advisory Committee on Conditions in Iron Foundries; and to act as a consultative body on matters which may be referred to it by H.M. Chief Inspector of Factories." It will be noted that the terms of reference require the committee to consider accident prevention—a feature with which the Joint Advisory Committee was not concerned. Accordingly, as soon as the more urgent research work on health aspects was well in hand, attention was turned to this important problem. In the committee's first

report*, it is stated that handling articles (including the lifting of heavy weights) and the movement of molten metal are together responsible for over 50% of the total foundry accidents each year. This total could be very considerably reduced by a concentrated and determined attack on the main causation groups, but, for such a campaign to be successful, there must be really keen interest and determination to succeed on the part of management, and equally keen interest and the fullest co-operation on the part of the workmen.

Because of the possible damage to workers' lungs arising from dust in the foundry atmosphere, there is a real and urgent need to reduce the amount of dust in foundries. The study of the problem has been greatly facilitated by the work of a member of the committee, Mr. W. B. Lawrie, M.B.E., who developed a rapid method of estimating dust content and a method of filming the movement of fine dust clouds. The elimination of dust should be the objective of every foundry, and any future change of practice which results in the achievement of this end will improve the foundry without the necessity for dust control equipment, thus saving money, floor space, and maintenance costs. A second method of dealing with dust is to avoid the use of materials or processes which produce a dangerous dust cloud. The substitution of a non-silicious parting powder in place of silica flour has not reduced the concentration of the airborne dust cloud resulting from its use, but, because of the absence of fine silica particles, it has eliminated the danger.

In many instances, the only practical means of dealing with the problem of dust will be by methods of dust control, and for this reason the committee has devoted a considerable amount of time and effort to this aspect. Details are given, in the report, of local exhaust ventilation methods applied to various types of grinder, to the pneumatic chisel, and to the "knock-out". In an attempt to eliminate dust at the source, a wet decorating bar has been developed which uses about 10 gallons of water an hour.

Finally, there is the matter of obnoxious fumes in the foundry atmosphere. Carbon monoxide can arise from the cupola, heating stoves, core stoves, mould dryers, and poured moulds; sulphur dioxide from coke fires; and other fumes from core binders. Improvements to foundry buildings may necessitate greater attention being paid to this problem in the future, owing to the absence of unintentional ventilation.

PRINTING TRADES DISPUTE

It is regretted that as a result of the dispute in the printing trade this issue is slightly reduced in size and will reach readers late. The publishers are not a party to the dispute and can only hope that as a result of the deliberations of the Court of Inquiry "normal service will be resumed as soon as possible."

* Questions in Iron Foundries—First Report of the Joint Standing Committee. 74 pp. London, 1956, H.M. Stationery Office, on behalf of the Ministry of Labour and National Service, 4s. 6d.

Meeting Diary

5th March

Institute of British Foundrymen, Lancashire Branch. "Melting of Non-Ferrous Metals in the Cupola", by M. G. CLIPSTON. Midland Hotel, Manchester. 7 p.m.

Institute of British Foundrymen, Sheffield Branch. "The Hardening of Moulds and Cores by the CO₂ Process", by Dr. D. V. ATTERTON. Sheffield College of Commerce and Technology, Pond Street, Sheffield, 1. 7.45 p.m.

6th March

Institute of Metals, Oxford Local Section. "Beryllium", by G. C. ELLIS. Ballroom of the Cadena Cafe, Cornmarket Street, Oxford. 7 p.m.

Institute of Metals, South Wales Local Section. "Metal Finishing Processes", by Dr. G. E. GARDAM. Department of Metallurgy, University College, Singleton Park, Swansea. 6.45 p.m.

Sheffield Metallurgical Association. "Some Recent Developments in Metallurgical Analysis", by G. W. C. MILNER. B.I.S.R.A. Laboratories, Hoyle Street, Sheffield, 3. 7 p.m.

7th March

Institute of Fuel. "Fuel Practice in Italy" by Prof. C. PADOVANI. Institution of Civil Engineers, Great George Street, London, S.W.1. 5.30 p.m.

North East Coast Institution of Engineers and Shipbuilders, Student Section. Senior Address, by Dr. T. W. F. BROWN. Bolbec Hall, Newcastle upon Tyne. 6.45 p.m.

8th March

Institute of British Foundrymen, Beds./Herts. Section. "Investment Casting Process", by D. F. B. TEDDS. Small Assembly Room, Town Hall, Luton. 7.30 p.m.

Institute of Fuel, Western Meeting. "Fuel Practice in Italy", by Prof. C. PADOVANI. Joint Meeting of West of England members of the Institute of Fuel with the Bristol Section, Society of Chemical Industry. The University, Bristol. 7 p.m.

Institute of Welding, South London Branch. "Welded Construction—1950 and After", by R. J. FOWLER. 2, Savoy Hill, London, W.C.2. 6 for 6.30 p.m.

Liverpool Metallurgical Society. "Recent Developments in Casting and Moulding Techniques", by Dr. A. H. SULLY. Liverpool Engineering Society, 9, The Temple, Dale Street, Liverpool. 7 p.m.

9th March

Institute of British Foundrymen, Tees-Side Branch. "Aspects of Steel Foundry Practice", by H. HART. Teesdale Hall, Head Wrightson & Co., Ltd., Thornaby-on-Tees. 7.30 p.m.

Society of Instrument Technology, Midland Section. "Instruments in the Iron and Steel Industry", by A. H. POPLER. Regent House, St. Philips Place, Colmore Row, Birmingham, 3. 7 p.m.

10th March

Institute of British Foundrymen, Scottish Branch. Annual Business Meeting and paper on "Experience with Fast Drying Materials for Moulds and Cores", by A. I. DONALDSON. Royal Technical College, Glasgow. 2.45 p.m. The Annual Dinner will be held in the Grosvenor Restaurant after the meeting.

13th March

Institution of Engineering Inspection, Leeds Branch. "Principles of Mechanical and Metallurgical Methods of Testing Materials", by J. W. POOLE. Theological Library, Leeds Church Institute, Albion Place, Leeds, 1. 7.30 p.m.

14th March

East Midlands Metallurgical Society. "Production, Fabrication and Properties of Titanium and Some Titanium Alloys", by Dr. N. P. INGLIS. Nottingham and District Technical College, Shakespeare Street, Nottingham. 7.30 p.m.

Institute of Metals, Scottish Local Section. "Uses of Oil Fuel in Melting Furnaces", by T. CHIPPINDALE. Followed by the Annual General Meeting. Institution of Engineers and Shipbuilders in Scotland, 39, Elmbank Crescent, Glasgow, C.2. 6.30 p.m.

Institute of Welding, Medway Branch. "The Training of Welders", by F. CLARK and J. STEVENS. Sun Hotel, Chatlam. 7.30 for 7.45 p.m.

Institute of Welding, South London Branch. Joint Meeting with Royal Aeronautical Society, Weybridge. "The Control of Welding Processes in Aircraft Production", by H. E. DIXON. Vickers-Armstrong (Aircraft), Ltd., Weybridge, Surrey. 6 p.m.

Institution of Production Engineers, Preston Section. "Pressure Diecasting", by T. BRADSHAW. Crown Hotel, Market Place, Blackburn. 7 p.m.

Manchester Metallurgical Society. "Some Metallurgical Problems Imposed by Stratospheric Flight", by Major P. LITHERLAND TEED. Manchester Room, Central Library, Manchester. 6.30 p.m.

15th March

Institute of Welding, North London Branch. "Lectures and Demonstrations by the Research Department". MUREX WELDING PROCESSES, LTD., Hertford Road, Waltham Cross. 7 for 7.30 p.m.

Institution of Production Engineers, Reading Section. "Mechanical Handling Techniques", by J. BAIN. Preceded by Annual General Meeting (members only). Great Western Hotel, Reading. 7 p.m.

Institution of Production Engineers, Southern Section. "Shell Moulding", by J. A. FALLOWS. Polygon Hotel, Southampton. 7.15 p.m.

16th March

West of Scotland Iron and Steel Institute. "Recent Investigations into the Chemistry of Open-Hearth Roof Refractories and their Bearing on Performance", by Dr. J. WHITE. 39, Elmbank Crescent, Glasgow. 6.45 p.m.

17th March

Institute of British Foundrymen, East Midlands Branch. "The Planning and Operating of a Mechanized Core Shop for the Blowing of Small and Medium Size Cores", by J. HILL. Gas Showrooms, Nottingham. 6 p.m.

20th March

Institute of British Foundrymen, East Anglian Section. "Propeller Manufacture", by J. M. LANGHAM. Central Hall, Public Library, Ipswich. 7.30 p.m.

Institute of British Foundrymen, Slough Section. Annual General Meeting, followed by "Precision Casting", by G. TOMKINSON. Lecture Theatre, High Duty Alloys, Ltd., Slough. 7.30 p.m.

Institute of Metals, Birmingham Local Section. "Soldering and Brazing Metallurgical Materials", by R. C. JEWELL. James Watt Memorial Institute, Great Charles Street, Birmingham. 6.30 p.m.

Institution of Engineers and Shipbuilders in Scotland. Joint Meeting with Greenock Association of Engineers and Shipbuilders. "Graphite and its Contribution to Industry", by E. R. BRAITHWAITE. The Lorne, Greenock. 7.30 p.m.

North East Metallurgical Society. "Powder Metallurgy", by Dr. I. JENKINS. Cleveland Scientific and Technical Institution, Middlesbrough. 7.15 p.m.

Sheffield Metallurgical Association. "Some Problems Associated with the Production of Heavy Forgings", by T. R. MIDDLETON. B.I.S.R.A. Laboratories, Hoyle Street, Sheffield, 3. 7 p.m.

21st March

Institute of British Foundrymen, London Branch. "Theory and Practice in Steel Castings Production", by J. F. B. JACKSON. Waldorf Hotel, London, W.C.2. 7.30 p.m.

Institute of British Foundrymen, North East Scottish Section. Annual Business Meeting, followed by "Review of the Foundry Industry", by J. WEBSTER. North Sea Hotel, Arbroath. 7.30 p.m.

Institute of Fuel. "Operational Studies of the Relationship between Coal Constituents and Boiler Fouling", by P. J. JACKSON and J. M. WARD; "Full-scale Trials of the Humidification of Combustion Air to Prevent Boiler Fouling", by A. M. FREEDMAN; "An Investigation into the Air-heater Corrosion of Oil-fired Boilers", by B. LEES. Institution of Civil Engineers, Great George Street, London, S.W.1. 5.30 p.m.

Society of Instrument Technology, Newcastle Section. "Flaw Detection in Metals", by J. BROWN. Stephenson Building, King's College, Newcastle. 7 p.m.

Aluminium Finishes for Exterior Use

By J. C. Bailey, B.Sc., F.I.M.,* and W. Evans, B.Sc., A.I.M.†

With the increasing use of aluminium in service conditions which include exposure to the atmosphere, as in building and transport, there is a growing interest in the various decorative and protective finishes which can be applied to aluminium and its alloys. The authors discuss anodising—plain or coloured—brightening, chemical finishes, electroplating, painting and vitreous enamelling.

A VARIETY of new structural materials is coming into use, particularly for the exterior cladding of buildings, and aluminium is receiving very close attention because of its durability and lightness. The potentialities of aluminium in this field were dramatically revealed by the completion in 1952 of the 37-storey headquarters of the Aluminum Company of America, in Pittsburgh, the whole building being faced with aluminium curtain walling finished in a pleasant grey tone achieved by anodising. This method of construction in aluminium has since been adopted for many other buildings: more recently, with the trend towards colour in external features of buildings, colour-anodised aluminium for exterior cladding has come into vogue.

Aluminium can be given a permanent bright reflective finish comparable with chromium plate, and this development is arousing interest primarily in the motor transport field. Bright aluminium trim and body fittings are now being produced in super-purity aluminium alloy, subsequently anodised under special conditions to yield a substantial and abrasion-resistant anodic film that will ensure long life and immunity from deterioration in even the severest environments. Such a development is a significant pointer to future trends, and one purpose of this brief review is to consider the technical advances that have made this and other developments possible. Another purpose is to review also the more familiar methods of treating aluminium surfaces that are to be exposed to the weather, both from the aspect of decoration and protection, so that a fairly complete picture is presented of the treatments now available to the designer, architect, and transport engineer.

It should not be overlooked that most of the aluminium used in structures and in industrial buildings is not protected in any way, as the materials selected from the wide range of alloy compositions available are usually those that are resistant to most atmospheres without the need for protective coatings. It is chiefly a desire for decoration and harmonious colour schemes, as well as preservation of a pleasing appearance throughout the years, that leads to the use of applied finishes on aluminium.

Developments in Anodising Techniques

Anodising is one of the principal surface treatments applied for decorative purposes, and anodising practice has developed steadily, following the lines indicated by the classic researches of Bengough and Stuart, whose patent for the chromic acid process was filed in 1923. In the last three years, however, papers have been published in the U.S.A.¹⁻³ that make fresh contributions

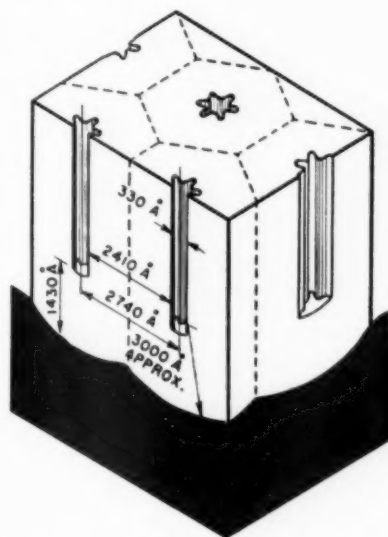


Fig. 1.—Structure of the anodic film formed in 4% phosphoric acid at 120 volts, showing the dimensions of the cell, pore and barrier layer.

to our understanding of the effects of anodising conditions on the characteristics of anodic films. Anodic films may be divided into two categories:

- (a) those produced in electrolytes having no solvent action on the anodic film, e.g., boric and tartaric acids.
- (b) those produced in electrolytes having a solvent action on the anodic film; e.g., sulphuric and chromic acids.

Films of the first type—described as barrier type films—are continuous and non-porous; the maximum thicknesses are shown to be a product of the applied voltage and a constant of 14Å . The structure of the second type of film is more complex. It consists of a thin continuous barrier type film, similar to those already described, sandwiched between the aluminium surface and an outer layer having a porous cellular structure. Keller, Hunter and Robinson¹, from electron microscope studies, showed that the cellular layer consists of unit cells having approximately hexagonal shapes. The thickness of the barrier type film in this instance is influenced by the electrolyte, temperature, and concentration, whilst the thickness of the cellular film is governed by time of anodising. Keller and his colleagues also studied the factors influencing the basic dimensions of the cellular film, and it is shown in their paper how

* Chief Metallurgist, The Aluminium Development Association.
† Metallurgist, The Aluminium Development Association.

TABLE I.—ANODIC FILM THICKNESS FOR VARIOUS SERVICE CONDITIONS.*

Application	Minimum Thickness			
	Chromic Acid Electrolytes		Sulphuric Acid or Oxalic Acid Electrolytes	
	in.	micron	in.	micron
Lighting Reflectors for Internal Use.	—	—	0.00020	5.1
Lighting Reflectors for External Use.	—	—	0.00040	10.2
Interior Decorative Work Coatings Exposed to Weather.	0.00010	2.5	0.00020	5.1
Coatings for Subsequent Painting.	0.00015†	3.8	0.00060	15.2
	0.00005	1.3	0.00020	5.1

* From B.S. 1615.

† This thickness is not obtainable on some classes of aluminium alloys.

each unit cell is formed around incipient pores by local current variations affecting the solvent action of the electrolyte. The diameter of the pores is governed by the electrolyte, whilst the wall thickness of the cells is dependent upon the forming voltage as well as the electrolyte, thicker walls being formed at higher voltages. Cell size is governed by forming voltage, increasing with increasing voltage. Fig. 1 shows the structure of anodic films formed in 4% phosphoric acid at 120 volts: the metal is shown in black. Under these conditions the thickness of the barrier layer is 1430 Å; the pore diameter is given as 330 Å, a constant for the electrolyte, and the wall thickness 1205 Å.

The practical significance of this work is that under known forming conditions the characteristics of anodic films can be predicted. More light is thrown on factors governing the porosity of anodic films, which is of value in the further development of techniques for dyeing and sealing them. An explanation is also provided for the superior corrosion resistance of the thinner films produced in chromic acid electrolytes, this being attributed to the existence of a thicker barrier layer.

B.S. 1615—"Anodic Oxidation Finishes for Aluminium and Aluminium Alloys"

Because of the wide range of films, having different characteristics, which can be produced in different electrolytes under various conditions of concentration and temperature, British Standard 1615: 1949 "Anodic Oxidation Finishes for Aluminium and Aluminium Alloys" was prepared as a guide to users of anodised aluminium, so that standards of quality could be established. This standard deals with the performance and testing of anodic films, and lays down recommended minimum thicknesses of anodic films for specific service conditions. The measurement of anodic film thicknesses, reflection factors for anodised surfaces, resistance to abrasion, and fastness to light of colour-anodised aluminium are also covered.

For external applications the standard specifies minimum film thicknesses of 0.00015 in. for films produced in chromic acid, and 0.0006 in. for films produced in sulphuric acid electrolytes. This clearly illustrates the superior corrosion resistance provided by the thinner films formed in chromic acid, due to the good barrier layer. The method given for measurement of the thickness of anodic films is as follows: a test piece of at least 5 sq. in., of a shape whose area can be easily determined, is weighed, and then the anodic film is stripped by immersion in an aqueous solution containing 3.5% phosphoric acid and 2.0% chromic acid at boiling point. After complete stripping the sample is re-weighed. From the loss in weight, surface area, and

the density of alumina, which is given as 2.5 g./ml., the thickness of the anodic film may be calculated. The method given for determining abrasion resistance is based on one described by Schuh and Kern⁴. In this test an abrasive powder of standard size is directed under air pressure on to an anodised test piece, and the weight of abrasive needed to penetrate the anodic film is quoted as a measure of its abrasion resistance.

Three methods for measuring the reflectivity of anodised aluminium are specified, together with a method for determining the light fastness of colour-anodised aluminium. In connection with the latter, the standard states that for exterior applications only dyestuffs with a light fastness of at least 7 should be used.

The experience that has been gained over the past six years, together with the new developments which are now taking place in the field of the exterior applications of anodised aluminium, indicates that the time is now ripe for a revision of B.S. 1615: 1949, and much preparatory work to this end has already been done.

The table in B.S. 1615 quoting minimum film thicknesses for performance in specific service conditions is reproduced as Table I. It is now felt that the figure of 0.0006 in which is stipulated for sulphuric acid films used externally may require further consideration during the revision now in progress; the trend is towards thicker films than this for exterior use. Nevertheless, the current edition of B.S. 1615 is a most valuable guide to good practice, and offers a ready means of setting a standard of quality of the anodic films for various requirements. It is a sound document which has been fully accepted by the leading anodising companies, and should be more widely used as a means of specifying anodising requirements, particularly where the material is to be installed in permanent buildings. It is also desirable that those contemplating the use of anodised aluminium should consult with the anodiser at an early stage in their deliberations regarding the finish desired, so that the most economical and, at the same time, most satisfactory finish on the component may be achieved.

Thick Anodic Films

It has generally been considered in the past that anodised aluminium, whilst giving excellent service indoors, is not really to be recommended for exterior use, due to gradual surface deterioration leading to an unsightly appearance. Such a view is based on the observed performance of aluminium to which only a thin anodic film has been applied, e.g., 0.0002 in. or less. Whilst such films may not be adequate for severe conditions of exposure, e.g., marine and industrial atmospheres, this scarcely applies in milder atmospheres: anodised aluminium windows and similar components are giving very satisfactory service, particularly if regularly cleaned. However, there is now a trend towards the use of considerably thicker anodic films, obtained by longer treatment in the anodising bath under appropriate conditions, and there is little technical difficulty in producing compact adherent films that are 0.001 in. thick or greater. Such films have a considerably longer life than those of lesser thickness, whilst retaining in full their ability to be dyed to various shades. It is thicker films of this nature that are being applied to the aluminium panels and curtain walling now being incorporated in permanent buildings, such as office blocks. The results of long-term exposure tests, mainly

carried out in the U.S.A., justify this new application. Sometimes the film is subsequently treated with a lacquer in order to preserve it from damage during erection, and the lacquer is claimed to weather off in a uniform manner that does not lead to unsightly contrasts.

In this country, anodisers have gained valuable experience in producing thick anodic films, but experience in dyeing them to various colours is limited, particularly on large surface areas. The new techniques required are being developed actively, and the need to ensure good colour matching is being taken into account. The use of stucco or patterned sheet may possibly help in solving some of these problems.

Colours for External Exposure

As already stated, B.S. 1615:1949 requires that dyestuffs used for colouring anodised aluminium for external applications should have a light fastness index of at least 7. Although the dyestuffs manufacturers offer numerous dyes with indices of 7 or 8, careful selection is necessary. Two manufacturers offer a range of dyestuffs which, when applied to anodic films, show little or no change after exposure to the weather for one year; the colours are gold, blue, bronze, red, violet and black. These colours, and others including green and pink, are being tested by British producers when applied to substantially thick films.

Recommended conditions for anodising in order to obtain maximum light fastness are given by Ciba, Ltd., for their Oxanal dyestuffs fast to weathering, as 16% sulphuric acid (by weight) at a current density of 14 amp./sq. ft. at a temperature of 18–20°C. for 30 minutes, for all colours except black, which requires 40 minutes. Such conditions do not yield the thick films now considered desirable for permanent buildings in industrial areas. However, a lower temperature, about 15°C., and a higher current density of about 20 amp./sq. ft., together with a longer anodising time, may be adequate. The films, of course, should be sealed, and one recommendation is a 0.5% solution of cobalt acetate or nickel acetate, buffered with 0.5% boric acid at 95°C.: the pH value of the sealing solution should be maintained between 5.6 and 5.8.

Clad Sheet

A material recently developed in the U.S.A. which is now available from British manufacturers is aluminium alloy sheet clad with an aluminium-5% silicon alloy. When this material is anodised in sulphuric acid a pleasant dark grey film is produced—due to particles of silicon occluded in the anodic film—and it offers to architects coloured aluminium that is non-fading and will weather very well indeed (see Fig. 2).

Bright Aluminium

In addition to the architectural applications where anodised aluminium is finding increasing use, many new possibilities equally attractive and interesting are being opened up by the use of super-purity 99.99% aluminium and super-purity-aluminium-base alloys treated to yield a surface of high specular reflectivity. In this instance, the finish on aluminium is comparable with chromium plate, with which it matches extremely well. The polished metal is brightened either chemically or electrolytically by such processes as the Erftwerk, Brytal or Alzak processes, to name but a few. The brightened metal is subsequently anodised to preserve the surface.



Fig. 2.—The Alcoa building in Pittsburgh, showing aluminium curtain walling and windows. The panels are in an aluminium alloy clad with an aluminium-5% silicon alloy and anodised to give grey coloured thick films. The windows are also anodised to give thick films in the natural colour.

Using super-purity aluminium, or one of its alloys, it is possible to achieve a total reflectivity after anodising of 83% or more, of which some 98% is specular. Typical chromium plating has a total reflectivity of about 63%, of which 99.7% is specular. (Total reflectivity is a measure of the brightness of a sample, whilst the specular component indicates the clarity of the image reflected by a flat surface.) In the Erftwerk chemical brightening process, the work is initially etched, either in a solution containing 70–90% nitric acid together with 10–30% hydrofluoric acid at room temperature for 10 seconds, or in a 10% solution of sodium hydroxide at 50°C. for 30 seconds. After rinsing, the work may then be brightened in a mixture containing 13% nitric acid, 16% ammonium bifluoride, and 0.02% lead nitrate at 50–80°C. for 5–30 seconds. The Erftwerk bath, which is covered by German patents and by British Patents 693,776, 693,876, and 738,711, exerts considerable solvent action on the metal, and for this reason careful control of the treatment time is needed. For the same reason, the bath is also capable of smoothing surfaces that have been only crudely polished, and can remove quite deep scratches leaving a smooth, polished, bright surface. This holds out a possibility of at least reducing mechanical polishing time and, in favourable cases, possibly eliminating it altogether, depending upon the shape of a particular component and the amount of cold work that it has received.

The well-established Brytal process is electrolytic and is a true brightening process, as distinct from a polishing and brightening process. The solution consists of 15% by weight of sodium carbonate together with 5% by weight of trisodium phosphate, mixed in water maintained at



Fig. 3.—The Pylumin treated aluminium roof of the First Church of Christ Scientist, Sloane Street, London. The Pylumin film was dyed green and the roof matches very well with its surroundings.

75–85° C. The work is made the anode, and is suspended in the bath for 10–30 seconds before switching on the current. After this preliminary etch a potential of 10–14 volts is applied and maintained for 5–8 minutes, when the work is removed and rinsed. Another electrolytic method for brightening is the Alzak process. The solution in this instance is 2.5% fluoboric acid in water at a temperature of 30° C., and is used at a current density of 10–20 amp./sq. ft. and a potential of 15–30 volts, either D.C. or A.C. The time of treatment varies from 5 to 10 minutes. Other electro-chemical baths are the Alcoa bath and the Battelle bath, based on phosphoric acids: they are more fully described by Brace⁵.

Operating experience with these baths in the treatment on a large-scale of super-purity base aluminium-magnesium alloys is being accumulated: a close comparison needs to be made of such important aspects as drag-out losses, maintenance of the bath in a satisfactory working condition, relative costs, ease of application, and consistent quality of product. Such data obviously are needed when decisions have to be made regarding large scale application of these processes, but the matter is now under active study, and in due course their relative merits will become more fully assessed.

It is clear already that different purities of aluminium and aluminium alloy respond in a different manner to the different processes. For example, the Ertwerk process and Brytal and Alzak electrolytic processes all find their chief advantages when applied to the super-purity metal or the super-purity aluminium-magnesium alloys. Experiments have been made with magnesium contents of $\frac{1}{2}\%$, 1%, $1\frac{1}{2}\%$ and 2%, and it seems that any higher magnesium content may lead to a lessening of the specular reflectivity, with consequent loss of brightness.

General Brightening Treatments

Bright finishes are not limited to super-purity aluminium, and treatments are available for brightening

commercial-purity metal (99.0% minimum aluminium) and metal up to 99.8% minimum purity, as well as some of the simple alloys containing magnesium or magnesium and silicon, and one or two casting alloys (e.g., LM5 and LM11, B.S. 1490).

The phosphoric/nitric acid baths exert a pronounced brightening action on commercial-purity aluminium and some of the alloys such as the aluminium-magnesium-silicon type, although the total reflectivity achieved, i.e., the brightness, is less than with the super-purity base materials. Although the metal is bright on removal from the bath, the subsequent anodising process causes a loss of brightness: nevertheless, a total reflectivity of 70% and greater can be achieved, which is ample for many requirements. The solutions used are usually concentrated acids operated at 100° C. or more, being mixtures of phosphoric and sulphuric acids, phosphoric-nitric-sulphuric acid, sometimes with additions of acetic acid or heavy metal salts. The Alpol, Alupol, Alubril and Kynalbright baths are of these types, and their compositions and characteristics have been described by Brace⁵.

Anodising of Brightened Aluminium

The anodising treatment given after brightening should be such as will ensure a fairly thick film, which is also resistant to abrasion through having a relatively high intrinsic hardness. This can be achieved by reducing the anodising temperature in the sulphuric acid bath. Such films, when developed to a thickness of 0.0004 in. or greater, provide a very durable finish to components that must withstand a considerable amount of handling as well as exposure to the weather—components on motor car bodies, for example, and parts of the exterior trim subjected to fairly severe use. It is in this field of use that keen interest in bright aluminium is at present centred, and in Germany much bright aluminium trim has been applied to the Volkswagen and other cars during the last three years or so, with very satisfactory results. The British motor car industry is now taking an active part in developing these finishes for British use.

Brightened aluminium is also being adopted for many small articles, e.g., household equipment such as teapots and other articles where a bright decorative finish amplifies the appeal to the customer. Although bright aluminium is a new development at present offering the main attraction to motor car stylists and others, the merits of commercial-purity aluminium and the suitable alloys from the General Engineering series of the British Standards Institution should not be overlooked. Although the finishes may not be as bright as chromium plate, they possess an attractive sheen. Many continental cars and some British models make use of aluminium or aluminium-magnesium alloys, brightened and anodised, for such items as radiator grilles, fascia panels, windscreen mouldings and similar items.

Tests for Bright Aluminium

The scope of the 1949 edition of B.S. 1615 is not fully adequate for anodic finishes of this type, and considerable attention is being given to the need for laying down requirements to be met by bright aluminium. It is necessary to set a standard for the brightness itself, for the thickness of the anodic film, and for its abrasion resistance, and for this purpose there are already tests available that could be used as an ultimate reference.

Both brightness and abrasion resistance can be checked by rough and ready methods, such as the actual appearance of the sample when placed side by side with a standard sample of satisfactory brightness, and by some form of crude scratch test for abrasion resistance; but some more exact method of assessment is desirable.

A reflectometer such as the Guild Optical Smoothness Meter has been used with reasonably reliable results for assessing the total reflectivity and the specular component on bright aluminium surfaces: with a little more experience in its use for this purpose, it should prove a satisfactory instrument for reference tests. Similarly, for assessing abrasion resistance, the Schuh and Kern test has been adapted: for routine testing, some simpler but less exact method of checking the properties of the film would be useful, but these tests are needed for ultimate evaluation.

It is important, particularly at this early stage in the development of bright aluminium finishes for components and articles, that a satisfactory standard of quality be generally agreed upon, so that inferior films with their inferior performance can be guarded against. Proper choice of material and of the brightening process to be used, and adequate anodising subsequently, can yield a very excellent surface capable of considerable rough usage without deterioration.

Maximum Bath Sizes for Sheet and Extrusions

The maximum size sheet which can be sulphuric acid anodised in this country without undue difficulty appears to be of the order of 4 ft. or 4 ft. 6 in. square, sometimes even a little bigger; the maximum length of extrusion that can be treated in sulphuric acid baths is about 24 ft., 16-18 ft. being a convenient length. Chromic acid anodising baths are generally bigger, and sheets of the order of 6 ft. square may be treated. The maximum possible length of extrusion that can be processed in this electrolyte is something like 40 ft.

Chemical Finishes for Aluminium

In recent years, interest has grown in simple chemical finishes applied to aluminium, primarily on account of their cheapness and ease of application. The Alcrom and the Pylumin proprietary processes, (the licences being held by I.C.I., Ltd., and Pyrene Co., Ltd., respectively) are, as stated in the section on the painting of aluminium, essentially pre-treatments given to aluminium prior to painting. However, the modification of weathering characteristics of aluminium given by these treatments, and the improved appearance, has recently led to them being used for wall cladding, sandwich panels and similar exterior uses on buildings.

The Alcrom process is an acid chromate treatment which imparts to aluminium surfaces a characteristic iridescent green sheen. The film produced is quite thin but compact, and slightly increases the abrasion resistance of aluminium. When used for colour effects, difficulty may be experienced in colour matching, particularly when large areas are treated. This colour variation is inherent in the process, and it must be recalled that it was developed solely as a pre-treatment for painting—the pleasant hue of the treated metal being incidental.

The Pylumin process is based on an alkali chromate solution, and produces on aluminium a thin greyish film. Again, this is essentially a pre-treatment process for paint adhesion. The film is capable of receiving

dyestuffs, however, and some very pleasing colours can be achieved: a range of them is now being tested for durability and light fastness. The administrative buildings of the A.W.R.E., Aldermaston, are faced with aluminium panels that were Alcrom treated, and there are other examples: at Sloane Square, London, S.W.1, the First Church of Christ Scientist has been re-roofed with aluminium tiles Pylumin treated and dyed. In both instances the colours harmonise well with the surrounding materials (see Fig. 3).

Although these chemical finishes on aluminium are being employed for exterior use, it has to be appreciated that, because of their extremely low thickness, they cannot be expected to be as durable as the anodic films of a substantial thickness that have been described earlier. There is no reason to suppose, however, that they will not give very good service, particularly under mild rural conditions, and should the time come that they need re-furbishing, this can be readily achieved simply by painting over, after scratch brushing the surface to remove loose deposits.

Plated Aluminium

Copper, tin and silver are metals which are commonly plated onto aluminium in the radio industries for improving electrical characteristics, as well as for providing surfaces suitable for lead/tin soldering. The pistons of internal combustion engines are sometimes chromium plated to improve their wear resistance, and chromium-plated tea and coffee sets are common domestic items. Examples of plated aluminium used in positions exposed to the weather are, on the other hand, less common.

A series of service tests has recently been started on chromium-plated aluminium strips attached to the front of public service vehicles in an industrial city. These were treated with various thicknesses of nickel and then given a chromium flash. In some cases very satisfactory results have been achieved, but in others there has been peeling of the deposits, leading to an unsightly appearance. These tests, which are still in progress, confirm that an adequate undercoat of nickel is required on aluminium, as on other metals, if satisfactory performance of the plating is to be achieved. The samples that have an undercoat of 0.002 in. of nickel are still in very good condition after two years' service.

Painting

For most outdoor uses the low and medium strength aluminium alloys are sufficiently corrosion resistant to be used in the bare condition, the added protection afforded by paint films being unnecessary. For decorative purposes, however, and also for the protection of the strong heat-treatable aluminium alloys in severe corrosive environments, aluminium surfaces are often painted.

Aluminium and its alloys in all forms may be painted quite easily, provided a few simple rules are observed. A wide range of paint systems may then be used and the life of paint films on aluminium, particularly on the more corrosion resistant alloys, is found to be longer than on other metals.

Like all other surfaces, the aluminium to be painted must be clean, dry, and free from grease. To provide maximum adhesion between the metal and the paint film, aluminium must be pre-treated to provide a suitable key for the paint. This can be achieved by

TABLE II.—CHEMICAL COMPOSITIONS OF DU PONT VITREOUS ENAMELS

Constituents	PbO	SiO ₂	Na ₂ O	K ₂ O	Li ₂ O	Na ₂ SiF ₆	SnO ₂
Type 2A (mol%)	15.3	54.7	10.6	—	9.9	—	0.5
Type 2B (mol%)	17.1	52.3	17.7	1.9	7.3	3.2	0.5

one of the following processes:—

- (1) mechanical roughening, e.g., scratch brushing, rubbing with pumice stone, etc.;
- (2) chemical dipping into one of many solutions, such as a chromic-sulphuric pickle (D.T.D. 915A), the M.B.V. process, or proprietary solutions such as Alcom or Pylumin;
- (3) swabs or pastes based on phosphoric acid; these are particularly useful for treating large assemblies and structures;
- (4) wash or "etch" primers: these formulations are based on zinc tetroxochromate or zinc chromate in a vinyl resin vehicle and incorporating a small amount of free phosphoric acid; they may be applied by dipping, swabbing or spraying;
- (5) anodising, which gives an excellent key for paint adhesion.

After pre-treatment of the work, a priming coat which is compatible with the complete paint system should be chosen. A common and very satisfactory priming pigment for aluminium, and one which also inhibits corrosion, is zinc chromate or barium chromate; primers containing lead compounds should not be used on aluminium.

In a recent paper to the Institute of Metals⁶, Clark describes the resistance to weathering in a severe industrial atmosphere of painted and bare panels in mild steel and various aluminium alloys. The materials investigated were, according to the code described in B.S. 1470-1476, S.1B ½H, NE.6, NS.7, NS.7 ½H, NE.7, HS.10W, HS.10WP, HE.10W, HE.10WP, HE.15WP, NS.3, NS.4 and NS.5, although the last three alloys were only used for a minor part of the programme. Numerous pre-treatments, including sulphuric acid anodising and proprietary treatments, were used in the tests, and a range of primers and cover paints was investigated. The panels were exposed on four sites in a large chemical factory for four years.

Clark concluded from these tests that painted aluminium was much more resistant to weathering than mild steel, and that the life of the applied paint was also longer, a finding which is of great importance in reducing maintenance costs. The painted mild steel had rusted after 16 months, but the painted aluminium had not deteriorated significantly after four years. The painted high strength alloys, particularly in the fully aged condition, were less weather resistant than the other aluminium alloys investigated, and the life of the paint applied to the high strength alloys was shorter than that of paint applied to the corrosion resistant alloys. Pre-treatment prior to painting was found to give added adhesion and better life, although no marked difference was detected in the various established pre-treatments themselves. Zinc chromate was found to be the best of the primers investigated, and linseed oil is described as a good vehicle for it, although other primers were found to be good. Furthermore, any well compounded paint gives satisfactory service. No evidence was found suggesting rapid breakdown of repainted areas on aluminium: after wire brushing, and repriming, the re-painted surface gave satisfactory service.

Vitreous Enamelling

Vitreous enamelling of aluminium presents some technical difficulties, now largely overcome. The properties required of the enamel are:—

- (1) a low fusion point, preferably not greater than than 500-510° C.;
- (2) good adhesion;
- (3) a high coefficient of thermal expansion;
- (4) good hardness;
- (5) a high gloss; and
- (6) good resistance to weathering.

Because of aluminium's relatively low melting point (659° C.), the frit must also have a low fusion point, and this has led to the development of frits based on lead. In the U.S.A., these frits are supplied by a few companies, notably by E. I. Du Pont de Nemours. F. J. Biechler and J. J. Meynis de Paulin⁷, in a paper presented to the Congres International des Materiaux pour l'Aviation et les Projectiles-Fusees, described work which had been carried out in collaboration with Du Pont on numerous frits at the Centre Technique de l'Aluminium, Paris. They concluded that two Du Pont enamels were superior to others tested (see Table II), as was shown also by tests in this country in 1950⁸. These frits were hard and glossy and stood up well to laboratory tests. An important characteristic of the enamelled product is its flexibility and good resistance to mechanical damage; even when dented or chipped it does not deteriorate rapidly in the atmosphere.

In Great Britain, development has been somewhat slower. At present, frits are not commercially available, although at least one firm is preparing to manufacture the frit, and is acquiring experience in the enamelling technique.

In the U.S.A., vitreous enamelled aluminium sheet and extrusions in various colours have been used for wall cladding,⁹ spandrels and veneers. Although the price of panelling compares unfavourably with vitreous enamelled mild steel (2.50 dollars/sq. ft. or more, compared with 1.40 dollars/sq. ft.), the tremendous weight-saving advantages offered by aluminium in the construction of multi-storey buildings, together with its greatly superior resistance to deterioration after accidental damage to the enamel coating, has proved sufficient to attract architects to use enamelled aluminium.

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New Transmission Line for Sudan

British Insulated Callender's Cables, Ltd., announce that the Sudan Light & Power Co. Ltd., have placed with them an order for approximately seven miles of 33kV. aluminium-sheathed impregnated pressure cable for the new transmission line from Burri Power Station, Khartoum to Omdurman. It is anticipated that installation work, which is to be carried out by the Sudan Light & Power Co., Ltd., with the assistance of British Insulated Callender's Construction Co., Ltd., will commence in the spring or early summer of 1956. The route will include a crossing of the White Nile.

The Interactions of Static Stress and Corrosion with Aluminium Alloys

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Existing knowledge from laboratory experiments and service experience on the susceptibility of aluminium alloys to stress corrosion and on methods of protection was reviewed, with particular reference to practical implications, in a paper presented at the Autumn Meeting of the Institute of Metals¹. The views expressed and information given by contributors to the discussion at that meeting have been taken into account by the author in preparing this article from the original paper. He has concentrated in this article on the more practical aspects of the subject.

MOST of the metallic elements form some alloys which are liable to failure by stress corrosion under certain conditions². The appropriate conditions vary considerably for the different metals, and it seems doubtful whether a single satisfactory and detailed theory can be developed for the mechanism of all stress corrosion. For simplicity and clarity this paper is confined to aluminium-base alloys.

The primary purpose of the paper is to endeavour to give a true perspective of stress corrosion from the practical point of view in the aluminium alloys* at present standardised in this country. The term "static stress" is used in the title of this paper to make it clear that fatigue conditions are not considered in detail. The general consideration of service design or experience should take into account various combinations of mechanical and corrosion effects which might possibly lead to failure. Consideration of these complex cases must be based, however, on information gained by investigations of the simpler component factors. The contribution of this paper to the complex problem is to review the information available on stress corrosion of aluminium alloys. Various interpretations of the term "stress corrosion" have been responsible for some confusion which has arisen in this field, which stresses the need for basing the review on a clear definition of the basic term.

Definition of Stress Corrosion

It is important to differentiate between

- (a) intercrystalline attack which can reduce mechanical strength, but is itself relatively unaffected by service loads, and
- (b) stress corrosion which is a true conjoint action of stress and corrosion,

since the latter is of a more insidious character and narrows the range of effective precautions against failure. The following definition of stress corrosion was published in 1945,³ received no adverse comment, is now widely adopted in this country, is a basis for research on the subject, and is used in this paper:

"The term stress corrosion implies a greater deterioration in the mechanical properties of the material through the simultaneous action of a static stress and exposure to corrosive environment than would occur by the separate, but additive, action of those agencies."

This definition excludes layer corrosion, which involves corrosion followed, and then accompanied by, distortion of the corroded metal by the pressure developed by the corrosion products. The stress involved results from corrosion and cannot be applied or considered as a separate agency. Layer corrosion, in fact, has far more common features with blistering and crevice corrosion, than with stress corrosion as it is generally understood.

It is not sufficient simply to expose a metal simultaneously to stress and corrosion in order to assess its susceptibility to stress corrosion. Comparable specimens must be exposed to the same corrosion conditions but without stress, and stress corrosion is only demonstrated if the stressed specimens suffer the greater deterioration. Failure of a specimen when simultaneously exposed to stress and corrosion can occur simply because weakening of the specimen by corrosion reduces the residual strength until it is less than the load applied. This is particularly true of intercrystalline corrosion, because of the notch effect which results from this type of attack.

It is also desirable to subject comparable specimens to similar stress while protected from corrosion, to check whether pure stress effects are confusing the results. These confusing stress effects, such as creep, are likely to be serious only at high stresses, so that if stressing of control specimens without corrosion is impracticable, the difficulty can be safely avoided by limiting the maximum stress to the commonly used testing level of 75% of the 0.1% proof stress of the particular metal.

Simple exposure to stress plus corrosion, without control specimens exposed to stress or corrosion alone, may well provide an adequate experimental method when the metal is known to be susceptible to stress corrosion. For example, this simple technique may be used for exploratory tests, especially when investigating variations in the corrosive environment.

The above principles apply mainly to the investigation of stress corrosion in laboratory tests or field trials. Investigation of any suspected service failures is much more difficult. Such failures in aluminium alloys can only be reliably attributed to stress corrosion if positive evidence of each of the following is obtained.

- (1) The fracture and subsidiary or branching cracks are intercrystalline, except, perhaps, for the final purely mechanical rupture (Fig. 2).⁴ There should be few branch cracks, and the subsidiary cracks should be relatively isolated compared with the network of intercrystalline penetration (Fig.

* When the term aluminium alloys is used generally in this manner in this paper it may be taken to include the various grades of pure aluminium.

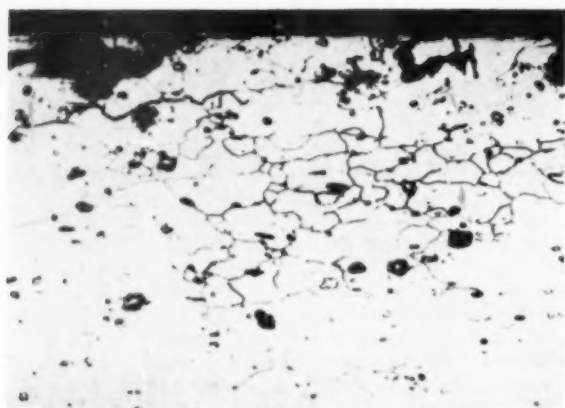


Fig. 1.—Intercrystalline corrosion of rolled aluminium alloy (HS. 14T inadequately quenched. Lightly etched). $\times 200$

- 1), often partly localised, which can occur in the absence of stress.
- (2) The metal must be known to have been subject to tensile or bending stresses while exposed to corrosion in service. Such stresses may be internal, e.g., residual from fabrication, or external due to service conditions.
- (3) The metal in the condition in which it was used must be known to be susceptible to stress corrosion. If this information is not available, laboratory tests should be made for the purpose, preferably on sound metal cut from the failed part.

In some instances, the breaking up or distortion of the crystals during previous working of the metal may give rise to difficulty in ascertaining whether the cracks are intercrystalline in character. The principle of paragraph 3 should then be applied, i.e., laboratory tests should be made to ascertain the detailed character of stress corrosion cracks formed in the laboratory in a sample cut from the failed member.

Mechanism of Failure

In the absence of complicating factors, such as galvanic effects or extreme acidity or alkalinity of the corrosive environment, the corrosion-time curve for aluminium alloys is of the asymptotic form (*A* in Fig. 3). If the metal is susceptible to stress corrosion, then the simultaneous application of stress accelerates the rate of intercrystalline penetration. This effect may be small during the early stages of exposure, so that initially the corrosion-time curve may still be of the asymptotic form. As the rate is accelerated, however, the form of the curve is radically changed, as shown in curve *B* of Fig. 3, and penetration eventually proceeds at such a rapid rate that the ultimate fracture is largely intercrystalline (due to stress corrosion), and only a small proportion of it is transcrystalline (due to the final mechanical failure). Moreover, this intercrystalline failure takes the form of a fairly isolated crack (*A*, Fig. 2) as distinct from the network of intercrystalline corrosion shown in Fig. 1; the final mechanical failure is shown at *B* in Fig. 2. Thus the major effect of stress in stress corrosion failure is concentrated in the later stage of the failure, but with the relatively rapid failure which can be obtained in the



Fig. 2.—Stress corrosion fracture in aluminium alloy under a tensile load equivalent to 75% of the proof stress (NS. 7 abnormally aged. Unetched). $\times 20$

laboratory the earlier asymptotic portion of Fig. 3*B* may not be observed.⁵⁻⁸

Stress corrosion cracks are generally intercrystalline in character: in fact the author is not aware of an exception to this with commercial alloys. Alloys susceptible to stress corrosion are subject to intercrystalline attack in the absence of stress, but the attack is much less localised, as shown, for example, by comparison of Figs. 1 and 2. On the other hand, the fact that an alloy suffers intercrystalline attack in the absence of stress does not indicate that it will suffer stress corrosion when stressed under corrosive conditions. The alloys which are susceptible to stress corrosion are, in fact, relatively few in number. The present author is dissatisfied with theories of the mechanism of stress corrosion which do not account for this important fact, and has proposed^{1,9} a modification of Dix's theory¹⁰ to bring it more in accordance with the observed facts. Since such theories are still a matter of controversy, they will not be discussed further in the present article.

Environment

Chlorides and moderately acid conditions¹¹ are most liable to cause intercrystalline corrosion or stress corrosion of aluminium alloys. Perryman and Hadden⁵ found

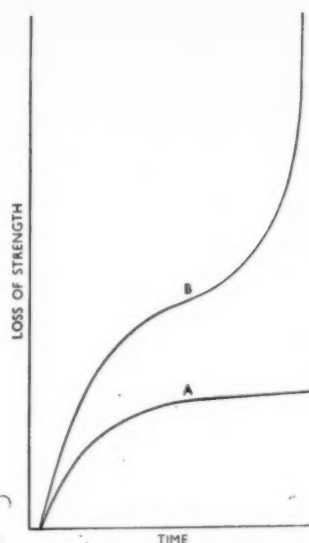


Fig. 3.—Idealised corrosion-time curves.

that the stress corrosion of an aluminium-7% magnesium alloy in a susceptible condition increased with increasing sodium chloride content, up to about 9%. With extreme acidity, general attack is more likely to occur, and serious intercrystalline attack or stress corrosion is not then observed, but the moderate acidity of a mixed marine-industrial type of atmosphere provides very severe conditions. Humidity is an important factor, and appears to have its maximum effect at about 80% relative humidity in salt spray tests⁵.

Stress corrosion of susceptible alloys can, however, occur in much milder conditions. Indeed, laboratory tests under moderately humid conditions, but with very little pollution of the atmosphere, have given stress corrosion (of abnormally aged 5L3) with extremely fine and isolated cracking, which was difficult to detect by visual inspection. Normally, however, the stresses present cause sufficient mechanical widening of the crack to render it visible to close inspection, and stress corrosion in service is normally associated with more corrosive environments.

The relative susceptibility to stress corrosion of different alloys may be dependent on the corrosive medium involved. In some laboratory experiments oxygen appeared to be essential for stress corrosion to proceed,^{5,11} but other experiments indicate that this is not a general rule for aluminium alloys¹².

Stress Conditions

The stress conditions used in laboratory tests may be divided into two main types, according to whether they approximate to constant strain or constant load conditions. The former approximate to internal stresses from production and to fabrication stresses, e.g., misalignment of rivet holes, while the latter approximate to service stresses. These stresses may be additive. The constant load type conditions are the most effective in causing stress corrosion in the laboratory, but in many applications, e.g., in aircraft, they reach high values only for short periods. In general, high internal stresses arising

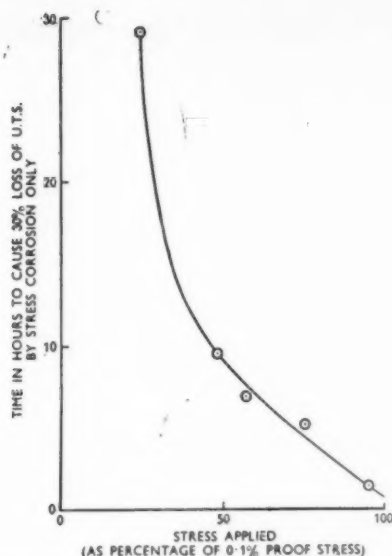


Fig. 4.—Example of effect of stress level on rate of stress corrosion. (NW. 7 abnormally aged).

from fabrication and assembly predominate as causes of stress corrosion failure in service.¹⁰ The continuous application of high constant loads in laboratory tests can make them more severe in relation to service conditions than they appear to be at first sight, and no doubt this partly accounts for the fact that far more stress corrosion has been observed in laboratory experiments than in service experience. Reference has already been made to other reasons for not using test stresses above 75% of the proof stress of the actual metal tested. Tensile stresses are usually more severe than bending stresses, while compressive stresses have little if any effect (e.g. ^{5,13}).

The rate of stress corrosion decreases markedly with reduction in stress, and there appears to be a limiting stress (the value of which will no doubt depend on the alloy and its condition) below which significant stress corrosion does not occur. An example is shown in Fig. 4 for aluminium-7% magnesium alloy intermittently immersed in 3% sodium chloride solution of pH 6.⁶

The orientation of the stress in relation to the wrought grain structure is important, stress corrosion being more likely to occur when the stresses are transverse to the elongated grain structure.¹⁴⁻¹⁶ Particular attention should be paid to this when machining complicated parts from extrusions or forgings of susceptible alloys.

Composition and Condition of the Alloy

The author is not aware of any reliable evidence of stress corrosion of the metals listed in Table I, in any conditions occurring in practice; this also applies to super purity aluminium, which is not at present included in British Standards. No reliable evidence of stress corrosion of cast aluminium alloys appears to have been published, and Table I is therefore confined to wrought alloys.

Standardised British alloys on which there is definite or suggestive evidence of some degree of stress corrosion are considered below. Stress corrosion susceptibility

TABLE I.—WROUGHT ALUMINIUM ALLOYS NOT SHOWN TO BE SIGNIFICANTLY SUSCEPTIBLE TO STRESS CORROSION

Alloys Specified in B.S.1470-6	Composition (%) ^a								Cladding
	Si	Fe	Cu	Mn	Mg	Zn	Cr	Al	
1A	0.15	0.15	0.02					99.8m	—
1B	0.3	0.15	0.5	0.05				99.5m	—
1C	0.5	0.7	0.1	0.1				99.0m	—
N.2	10.0-13.0	0.6	0.1	0.5					—
N.21	4.5-6.0	0.6	0.1	0.5					—
N.3	0.6	0.75	0.15	1.0-1.5					—
N.4	0.6	0.75	0.15		1.75-2.25		0.5		—
N.5	0.6	0.75	0.15	1.0	3.0-4.0	0.1	0.5		—
H.9	0.3-0.7	0.6	0.15		0.4-0.9	0.1			—
H.10	0.75-1.3	0.6	0.15		0.4-1.5	0.1	0.5		—
H.C.14†	0.7	0.7	3.5-5.0	0.4-1.2	0.4-1.2				1B
H.C.15†	0.9	1.0	3.5-4.8	1.2	0.85				1B
D.T.D.68†	0.5	0.5	1.5	0.3-1.0	2.0-3.5	4.5-6.5	0.5		Al-1%Zn

N.B.—It does not follow that alloys not listed here are subject to stress corrosion under all conditions of usage (see text).

^a m = minimum; other single figures are maxima.

† Resistance to stress corrosion dependent on cladding.

has been observed much more frequently in laboratory experiments than by actual service experience, and the two sources of information are therefore considered separately.

Laboratory Tests and Field Trials

Of the alloys which are not normally heat treated for the development of the required mechanical properties, stress corrosion has been observed only in the aluminium-magnesium alloys of high magnesium content: moreover the latter are not susceptible in the as-manufactured condition.⁵ The actual percentage of magnesium required to introduce susceptibility is doubtful, but is probably of the order of 5%. Most of the laboratory work has been concerned with the aluminium-7% magnesium alloy (N.7)*, which is rendered susceptible by ageing at moderately elevated temperature, especially if the ageing is preceded by cold work: for example 10% over-strain followed by 24 hours at 125°C., or a much longer time at tropical temperature, makes the alloy highly susceptible. Such ageing of the aluminium-magnesium alloys listed in Table I increases susceptibility to intercrystalline attack, but has not been found to introduce susceptibility to stress corrosion. With suitable cold work and ageing treatments, alloys in the N.6 range, and containing 4.65% or more magnesium, have shown susceptibility to stress corrosion in laboratory tests, but to a much less degree than with 7% magnesium (N.7).^{6, 17, 18}

The aluminium-10% magnesium casting alloy, B.S.1490 LM.10, has been found to fail more readily under stress corrosion conditions when slowly cooled from solution treatment (which also gives inferior mechanical properties), than when heat treated within the range of commercial practice.¹⁹ No data was provided on the behaviour of these specimens when exposed to corrosion in the absence of stress, so that convincing evidence on the susceptibility of this alloy is still lacking.

The aluminium-copper-magnesium alloys (H.13 and H.14) are not susceptible to stress corrosion when efficiently quenched and naturally aged: even with very inefficient quenching they show only slight susceptibility, although they are then strongly susceptible to intercrystalline corrosion. With abnormal thermal treatment such as stoving after painting they are markedly susceptible, especially if such thermal treatment is preceded by cold work.

The aluminium-copper-magnesium-silicon alloy in the solution treated and naturally aged condition (H.15W)

shows susceptibility to stress corrosion only if inefficiently quenched.¹⁴ When maximum mechanical properties are developed by artificial ageing (to give H.15WP), or when the solution treated alloy is subjected to a moderately elevated temperature, and especially after cold work (as, for example, in the stoving of formed and painted parts), then serious stress corrosion can occur.

The aluminium-zinc-magnesium alloys (e.g., D.T.D. 363), which give the highest mechanical properties, are susceptible to stress corrosion, particularly when the stress is applied in the short transverse direction. Research is actively proceeding on the composition and heat treatment of these alloys.

To sum up, laboratory tests have indicated a serious risk of stress corrosion in N.7 (only when aged, for example at tropical temperatures), H.14T (only when carelessly heated after the normal solution treatment), H.13T and H.15W (only when inefficiently quenched), H.15WP, and the D.T.D.683 type. There may be a very slight risk with N.6 when it has been aged, for example, at tropical temperature. The general inference from these conclusions is that the risk of stress corrosion of practical importance is introduced by the development of the highest mechanical properties by alloying and heat treatment.

Service Experience

No definite examples of stress corrosion failure of aluminium alloy castings in service are known to the author: this may be due partly to the relatively low stresses to which they are normally subjected. Stress corrosion has been suspected in some casting alloys of the aluminium-zinc-copper type, which are markedly susceptible to structural corrosion, but, unfortunately, no detailed investigation was made and convincing evidence is, therefore, not available.²⁰ In any case, these alloys should not be used under corrosive conditions without adequate protection, and in this particular case the trouble was overcome by the use of a more resistant alloy, LM.6. The experience of the Royal Aircraft Establishment is still as given by George and Chalmers.^{21, 22} Stress corrosion failures in British aircraft are extremely rare, in spite of the high stresses employed, and have been observed only in the wrought forms of aluminium alloys. Those containing a high percentage of zinc (e.g., D.T.D.363) or 21% copper, 1½% nickel, 1% magnesium and 1% iron (H.12) were stated to be highly susceptible. Aluminium-magnesium rivets containing 5% magnesium failed by fracture at the junction of head and shank when used on aircraft in

* The nomenclature of B.S.1470-6 is used where applicable.

tropical service. George and Chalmers considered the fracture to be due to stress corrosion, but Metcalfe¹⁷ investigated them in more detail. He found that they contained 4.6% magnesium, that the cracking was less localised and less marked than in rivets containing 7.0% magnesium, and, in the absence of conclusive evidence, attributed the fracture to "intercrystalline corrosion, *probably* accentuated by stress." Aluminium-5% magnesium (N.6) aircraft rivets are not normally used now for jointing aluminium alloys, mainly because of inadequate shear strength. No stress corrosion failures have been experienced with wrought aluminium-magnesium alloys containing less than 4.5% magnesium or with aluminium-magnesium alloy castings. D.T.D.363 alloys were used during the war with only anodising followed by painting as protection, but no case of failure in service by stress corrosion is known. German metallurgists, who often have a wider interpretation of the term stress corrosion than is used in this paper, examined crashed British aircraft and stated that they found no failures which could be attributed to stress corrosion. The suggestion has been made that stress corrosion has been a contributory factor in some failures of D.T.D.683 (D.T.D.363 type) forgings, and in an isolated case in D.T.D.364 forgings (H.15WP), but this matter is still under investigation.

There appears to have been only one failure in aircraft of the Royal Navy which could be attributed to stress corrosion, and this occurred in components fabricated from an aluminium-copper-magnesium-silicon-nickel alloy (H.12). They were anodised and painted only, and failed by cracking after 3 years' service. No stress corrosion failures of aluminium-5% magnesium rivets have been observed in naval aircraft²³. Thousands of tons of aluminium-magnesium alloys containing up to 5.5% magnesium have been used during and since the recent World War in the construction of naval ships: the alloys were largely in a cold worked condition, and many of the ships spent a considerable time in tropical waters: laboratory tests indicate that some susceptibility would be developed in these circumstances, but, in fact, no stress corrosion failures have been observed. Aluminium-7% magnesium alloy plate used in ships has given serious trouble, which may have been due to stress corrosion.

To sum up, there is some evidence of isolated service failures due to stress corrosion in the D.T.D.363 and H.12 types of alloy, and possibly in H.15WP and N.7. There have possibly been stress corrosion failures of N.6 rivets in aircraft, but naval experience of N.6 in various forms in aircraft and ships has been entirely satisfactory with respect to stress corrosion. There have been no stress corrosion failures in casting alloys, or in any of the wrought alloys given in Table I. Finally, it should be noted that all the alloys mentioned earlier as involving a serious risk of stress corrosion, according to laboratory tests, have been used in service for stressed members, and often in circumstances where protection such as cladding could not be provided, but that failure of aluminium alloys in service by stress corrosion is very rare.^{14, 21}

Alloys which have been widely used (in the given condition of heat treatment) without protection such as cladding or metal spraying are listed in Table II. Protection against other corrosion effects, e.g., by painting, may be desirable, depending on the alloy and environment.

TABLE II.—WROUGHT ALUMINIUM ALLOYS NOT NORMALLY REQUIRING PROTECTION AGAINST STRESS CORROSION (Additional to Table I)

Alloys Specified in B.S.1470-6	Composition (%) ^a					
	Si	Fe	Cu	Mn	Mg	Cr
N.6	0.6	0.75	0.15	1.0	4.5-5.5	0.5
H.13T ..	0.7	0.7	1.5-3.0	0.5	0.2-0.5	
H.14T ..	0.7	0.7	3.5-5.0	0.4-1.2	0.4-1.2	
H.15W ..	0.9	1.0	3.5-4.8	1.2	0.85	0.2

^a Single figures indicate maxima.

Protective Measures

It is common practice with engineers to make a "corrosion allowance," particularly for steel, when deciding on the thickness of metal required. Increase in thickness is particularly advantageous when the corrosion-time curve is asymptotic.²⁴ On the evidence at present available, however, with aluminium alloys subject to stress corrosion the advantage of increase in initial thickness is limited to the reduction in stress per unit cross-sectional area which it gives for a given load: it is this fact, in particular, which makes it important to differentiate between stress corrosion and simple intercrystalline corrosion. The following is restricted to protection against stress corrosion: protection against other forms of corrosion differ in some instances.

Every endeavour should be made to avoid high stresses resulting from fabrication and assembly. With large cross-sectional areas in alloys to be heat treated it may be necessary to reduce the quenching rate from solution treatment (e.g., by quenching in hot water) in order to reduce internal quenching stresses: since this may introduce or increase susceptibility to intercrystalline corrosion with some alloys, it is evidently necessary to consider cases individually. Internal stresses due to cold work can be minimised by forming heat treatable alloys in the annealed condition: subsequent solution treatment, required to give the appropriate mechanical properties, will then relieve the forming stresses. Otherwise, thermal stress-relieving treatments are not usually applicable to wrought aluminium alloys. Promising results have been obtained in the laboratory^{5, 25} by partially neutralising tensile stresses in the surface by means of compressive stresses induced, for example, by shot peening. Such methods must be used with caution, however, since the induced surface stresses may possibly accelerate ageing of the metal to a condition which is more susceptible to stress corrosion, as for example with the binary alloys of high magnesium content. Careful design of parts to avoid high local stresses and stress-raisers is evidently very important, especially with stresses transverse to the "fibre" of the metal.

The most effective protection based on service experience consists of the pure aluminium cladding rolled on to aluminium-copper-magnesium and aluminium-copper-magnesium-silicon alloys (to give HC.14 and HC.15 respectively). The author is not aware of any case of stress corrosion of these alloys, either in the laboratory or in service, where they have been adequately clad. The same is true of the aluminium-1% zinc alloy cladding rolled on to the aluminium-zinc-magnesium-copper alloy (D.T.D.363 type) to give D.T.D.687: service experience is less extensive with this metal than with the HC.14 or HC.15 type of alloy, but does extend to about 10 years. The copper content of the H.14 and H.15 alloy ensures that the pure aluminium cladding of HC.14 and HC.15 is adequately anodic to the core, but,

owing to the high zinc content of the D.T.D.363 type of alloy, an aluminium-1% zinc alloy is specified in D.T.D. 687 to give an anodic cladding. It should be noted that in such cases the cladding thickness is a fixed percentage of the total metal thickness. Consequently, if very thin clad sheets are used the cladding will be so thin as to allow serious diffusion of copper into it during the thermal treatments necessary during production, with consequent reduction in the protection provided to the underlying strong alloy. Subjection to elevated temperatures during service may also lead to such diffusion to a harmful degree.

With H.15 extrusions and forgings, a sprayed coating of pure aluminium should give adequate protection, since it has been shown to give adequate protection to H.15 extrusions when they are exposed to corrosion in the absence of stress,²⁶ while laboratory tests^{7, 10} and experience with rolled-on cladding show that stress corrosion is prevented by cathodic protection. Stress corrosion tests now proceeding on sprayed aluminium coatings on HS.15 support this view.¹⁵ Sprayed coatings of aluminium-base alloys would be expected to give adequate protection to other extrusion and forging alloys, provided the alloy coating is of a suitable composition to render it appropriately anodic to the core alloy. Excessive potential difference between core and cladding should be avoided, since it is liable to give undue wastage of the cladding by corrosion.

For many conditions of exposure, no further protection is necessary over the cladding or sprayed coating, but under very severely corrosive conditions (and especially if the thickness of coating is inadequate) these coatings may be corroded away eventually over areas too large to permit sacrificial protection of all the exposed core alloy. For exceptionally long life under such conditions, therefore, further protection may be provided, for example, by painting. Anodising is not recommended for this purpose (even as a preparation for painting), since it is likely to interfere with the sacrificial protection of the core. The other methods of ensuring good paint adhesion, such as the use of a pre-treatment or "wash" primer, can be employed (although this is usually unnecessary with sprayed coatings), and followed by a full chromate primer and then a waterproofing top coat. If paint films are not adequately maintained they can become harmful when deteriorated: where adequate maintenance is not possible, therefore, it is preferable to ensure that the coating thickness is adequate (at least 0.005 in.) to leave the coating unprotected, and to effect local repairs to the coating by metal spraying if and when that becomes necessary. When a cladding or sprayed coating is not employed, then anodising is decidedly advantageous as a preparation for painting, and such a system has given adequate protection on service aircraft as mentioned earlier, but this system must be regarded as less reliable than protection relying on anodic metal coatings.²² Where susceptible alloys are used in the form of bolts, the overall paint system should be supplemented by chromated jointing compound (D.T.D.369A) applied to the bolt before insertion.

The sacrificial protection afforded by anodic cladding should also be applicable by separate anodes connected to the susceptible alloy,^{7, 10, 27} although the author is not aware of service experience with this. Conversely, stress corrosion of a susceptible alloy might be stimulated by contact with a cathodic metal.

Summary and General Conclusions

Most aluminium alloys have not shown stress corrosion failure, even though some are susceptible to inter-crystalline corrosion, but the use of alloy compositions and heat treatments designed to give the highest mechanical properties tends to result in susceptibility to stress corrosion to various degrees. Stress corrosion failures in service are very rare, and, in fact, far more stress corrosion has been observed in the laboratory than in service, partly because the laboratory results have been used to minimise the risk of stress corrosion in service, and partly because laboratory tests have included conditions more severe than those experienced in service. The latter is evidently advantageous in providing a safety margin, but care must be taken that excessive safety margins do not place unnecessary restrictions on the alloys available to the engineer. For example, confusion by factors such as creep effects can be avoided, and better correlation with service experience obtained, by limiting the stress in laboratory tests to not more than 75% of the 0.1% proof stress. Tensile stresses have more effect than bending stresses, while compressive stresses have no practical importance: where the structure of the metal is markedly directional, stresses parallel to that direction are much less harmful than those normal to it. Industrial-marine atmospheres are liable to give the most severe effects, especially at about 80% relative humidity, but quite mild atmospheres may cause serious effects in a markedly susceptible metal.

Thicker metal is advantageous when it reduces the stress per unit area and, in general, much can be done at the design stage to minimise corrosion risks. Rolled-on cladding offers the maximum protection, and sprayed metal coatings appear to be as effective. Painting has been effective in some applications, especially when preceded by anodising and supplemented, where necessary, by suitable jointing compounds.

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Aluminium and its Alloys in 1955

Some Aspects of Research and Technical Progress Reported

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The Aluminium Development Association

Attention is drawn to work published in this country and the U.S.A. reporting research and technical progress in the various aspects of the metallurgy of aluminium and its alloys, including extraction, founding, fabrication, constitution, properties and standardisation.

Reference is also made to interesting applications of these materials.

ON March 30th, 1855, Michael Faraday showed to an audience at the Royal Institution the first piece of aluminium made in Britain, which had been extracted by the chemical process developed by Deville in France the previous year. In the succeeding century, aluminium has progressed so rapidly that a greater volume of the metal is now produced yearly than of all the other non-ferrous metals taken together; it is well established as the world's most important metal after iron. It was therefore specially appropriate that from June 1st to 10th, 1955, the aluminium industry of this country, through the Aluminium Development Association, should hold its Centenary Exhibition, which was honoured by a visit from H.R.H. the Duke of Edinburgh. The Exhibition illustrated the present position of the industrial application of aluminium and its alloys, together with a glance at the metal's history and some inspired prophecy about its future.

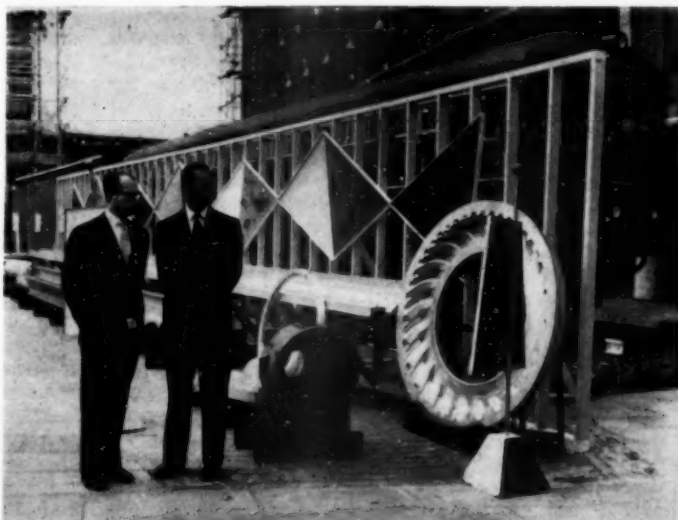
The scene was set¹ in an article which traced briefly the milestones in aluminium development, and how, by foresight and confidence in the future, the primary producing industry has provided the necessary metal to keep pace with steadily increasing demand. Zeerleder² gives details of the changes and improvements in alloy composition and treatment through the years, and reveals how, although there are still important

differences in usage in different countries, broad similarities are universal. As to the Exhibition itself, held at the Royal Festival Hall, several full and well-illustrated accounts have appeared.³⁻⁶ Over a thousand individual exhibits were included, and in addition to displays devoted to history, extraction and semi-fabrication, research and the future, twelve applications sections covered aircraft, road transport, marine applications, railways, building, agriculture and food, packaging, consumer goods, and structural, electrical, chemical and general engineering. Throughout the exhibition, six principal advantages of aluminium and its alloys formed the theme, namely, lightness, strength, permanence, good finish, high conductivity, and non-toxicity. All except the best-informed guests expressed their considerable astonishment at the variety of applications of aluminium in the modern world, as exemplified by the exhibits, and this might well be taken as a measure of the success of the whole venture.

Production

The atmosphere of centenary has led authors to look at progress in many branches of aluminium technology, and extraction has been no exception. It is possible to make an interesting comparison of the views of three writers of different nationality—British, Swiss and American—

H.R.H. The Duke of Edinburgh at the Aluminium Centenary Exhibition at the Royal Festival Hall, London, (accompanied by Dr. E.G. West, Technical Director of A.D.A.) inspects the outside exhibits, illustrating the production (from bauxite) of aluminium, and the semi-fabricating processes of rolling, forging, pressing, casting, extruding and spinning the metal. At the extreme right is a huge tyre mould in aluminium. In the background can be seen a diesel train in which the metal is widely used.



and to see how closely they agree about the remarkable consistency of the methods used for the production of virgin aluminium during the past sixty years. Chilton⁷ sees it as indirect evidence of the valuable properties and industrial versatility of the metal that the entire growth of the world aluminium industry—from 100 tons or so in 1890 to an estimated 2½ million tons in 1954—should have been based throughout on the same type of raw material (bauxite), the same chemical process for producing alumina (Bayer), and the same electrolytic reduction process (Hall-Héroult); and that these materials and processes should still hold the field practically unchallenged. Zeerleder⁸ has listed and discussed the principal extraction methods put forward in the last five decades in competition with the Bayer or Hall-Héroult processes, or both, and he concludes that none of them has found prolonged industrial application, with the exception of the Pedersen process, used under very special circumstances in Norway. While reaching very similar conclusions, Frary⁹ notes the present use in Arkansas of the Combination variant of the Bayer process, which can tolerate up to 13% silica in bauxite, alumina carried into the mud by silica present as clay being recovered by sintering with lime and soda. He describes clearly how the Bayer and Hall-Héroult processes, while they have persisted in principle, have been improved immeasurably in detail, resulting in a much purer product at a lower price. This author seems to consider that the sub-halide process faces, at present at any rate, insuperable difficulties in its chemical engineering requirements, and so is not likely in the foreseeable future to enjoy commercial application.

One of the spurs to investigators of possible methods of extracting alumina from ores other than bauxite is the danger of war interfering with bauxite importation; thus the U.S. Bureau of Mines was responsible for a project on the extraction of aluminium-silicon alloys from clays, and Banning and Hergert¹⁰ have described the results obtained. With a smelting technique using "hogged" wood (a mixture of chips, splinters and sawdust), they produced alloys containing just under 50% of aluminium, and feel that more experience might enable this proportion to be increased. Working on more conventional lines, Russell, Edwards and Taylor¹¹ have determined the solubilities of alumina hydrates in sodium hydroxide solutions under the conditions of the Bayer process, and compared their findings with those of other workers in this field. The results are expressed graphically and as tables, and show the effect of varying states of hydration of the oxide.

Expansion is the watchword of the aluminium extraction industry throughout the world; a steady increase in demand is forecast, and every effort is being made to meet it. Thus the French aluminium industry has in the past three years nearly regained its pre-war proportion of the world's production, and accounted for 7% in 1954; as against a world doubling of production each decade, French expansion was 46.6% in the three years ending in 1954. This is brought out in a brief but informative article by Moyal¹², who also directs attention to projected French expansions into the Cameroons and French Guinea. With the Kitimat smelter in production in Western Canada, interest centres on its planned expansion, and the importance of this development to the U.K. aluminium industry has been described¹³. An excellent piece of news¹⁴ released during 1955 concerned the formation of the Canadian British

Aluminium Company and its plans to build at Boie Comeau, on the north shore of the St. Lawrence river, a smelter to produce 40,000 tons by 1957 and 160,000 tons when fully completed. Another addition to the Commonwealth facilities for aluminium extraction was made when the Australian Prime Minister's representative opened the Australian Aluminium Production Commission's £10½ million plant at Bell Bay in Tasmania¹⁵. This smelter, working on Malayan bauxite, will eventually produce 13,000 tons of metal annually.

All the foregoing schemes depend upon water power as a source of cheap electricity, but many countries have little of such power available or capable of being harnessed. Much interest is therefore being taken in power generated from fuel, which is already in extensive use for aluminium production in the United States, and Johnson¹⁶ sees coal as the important future source of electricity for aluminium smelters. Comparing costs of aluminium production in Western Canada (water power) and in Illinois (steam from coal), he shows that when capital cost and transport charges are taken into account, power from cheap coal may well be economically advantageous.

As demand for aluminium increases, the necessity grows for efficient collection, processing and re-use of that valuable source of aluminium alloys, scrap. Capitaine¹⁷ has written briefly on the sorting of scrap, and gives a series of chemical spot tests to aid in this. An Institute of Metals informal discussion was devoted to the treatment of swarf and residues¹⁸, as a contribution to which Scheuer described in detail techniques used to clean, sort and remelt fine aluminium scrap.

Melting and Casting

One of the advantages of metals, as compared with some other materials of construction, is the comparative facility with which, by elevating their temperature, they may have their composition and shape changed, and, so to speak, a new start may be made. Before wrought forms can be produced, a cast piece must be made upon which work is subsequently done to obtain the shape and metallurgical condition required. For this, a furnace is essential, and aluminium presents fewer melting problems than some metals because its temperature of fusion is fairly low, although its thermal capacity is high. Nevertheless, Thackwell¹⁹ has shown that considerable difficulties have stood in the way of the development of large twin-bath induction furnaces for aluminium alloys, principally associated with the problem of obtaining a suitable refractory lining. Selecting an acid refractory of silica clay and quartz, sometimes with an addition of sodium silicate, he describes in fair detail the design and production of a rammed monolithic lining fulfilling the arduous requirements which he lists at the beginning of his account; also included are instructions for drying the lining and firing it *in situ*. Having melted the metal, its composition must be adjusted and its gas content reduced to acceptable levels; Capitaine²⁰ has given a very brief summary of semi-continuous casting of aluminium alloys, with recommendations as to rates of lowering of the billet or slab, according to the hot cracking tendency of the alloy being cast.

It has been said that the true home of the metallurgist is the foundry producing castings, and certainly the literature about aluminium alloy castings continues to grow apace. In the spirit of centenary, Fenn²¹ reviewed the growth of the aluminium foundry industry since late

in the last century, and included some interesting photographs illustrating important milestones in progress over the years. One result of reading an article such as Fenn's is a realisation that there is less that is new under the sun than might be gathered from contemporary statements about recent developments. Fletcher²², however, illustrates by examples how new cast alloys of aluminium have been added to those originally used, so that strengths as high as 22 tons/sq. in. with 18% elongation on a 2-in. gauge length may be offered. Again, the photographs accompanying this article are themselves a clear indication of the new fields into which aluminium alloy castings have penetrated.

One of the highly significant changes in the casting of aluminium alloys has been the more rapid increase in the production of gravity and pressure die castings than of sand castings, a true indication of the larger markets being served. Woollard²³ explains the advantages—economic, technical, and in the simplification of production—to be obtained by using die castings, and includes in his brief survey design factors, alloy choice, and machine requirements and variables. A promising branch of the die-casting process is that employing low pressure, and the use of this method to cast beer casks and barrels has been described²⁴. The containers are made in halves, subsequently joined by argon arc welding; barrels as large as 22 gallons capacity are fabricated in this manner.

An interesting example of the versatility of pressure die casting is the 49cc. two-stroke Teaghi engine²⁵; the finned cylinder, crankcase and an outrigger bearing bracket are cast integrally in alloy LM.2M, an undercut section in the cylinder barrel being provided by the use of a sectional core.

After lauding the efforts of the founder, it may seem incongruous to turn to methods of recovering castings not quite up to requirements. Nevertheless, when a large casting is machined and shows minor defects, blowholes and the like, it is economically quite indefensible to scrap it, if, by intelligent repair, it can be put into service with complete satisfaction. A new tool for such repairs is the Dot-Weld process^{26, 27}, the equipment for which consists of an electrode and holder carrying 220-volt alternating current, the electrode being vibrated by compressed air. By this means a spray of molten metal is directed on any area of a casting and quenched on impact by a stream of air around the electrode. It is stated that an electrode suitable for aluminium is available, but no mention is made of how any difficulties due to the oxide film are overcome. Another common defect of castings is porosity, resulting in lack of pressure tightness; while this may often be due to poor foundry technique, certain aluminium alloys, attractive because of high strength, ductility and corrosion resistance, are very difficult to make into pressure-tight castings. The founder must have recourse to impregnation, and a new method for this has been described²⁷, which requires no baking, but uses a medium resistant to temperatures of up to 450° C.

Working

Again in 1955, the Institute of Metals held one of its invaluable symposia on quality control in the manufacture of wrought products in non-ferrous metals, and three of the excellent papers presented were concerned with aluminium; the general field covered was heat-treatment and final operations. Field and Salter²⁸ deal

with rolled, extruded and drawn products, and this paper, particularly as regards sheet and strip, is a veritable *vade mecum* for the works manager and metallurgist; full details are given of all processes, and the measures taken to ensure quality at all stages. This applies especially to the preservation of good surface on sheet and strip during such operations as shearing and roller levelling, where small particles of metal and dirt can play havoc, and have to be continuously removed by suitable equipment. The paper on aluminium alloy drop-forgings was provided by Edmunds and Lloyd²⁹, who emphasise the importance of close collaboration at the design stage between supplier and user, to ensure the minimum of difficulty in the forging operation; such things as adequate radii are among the more obvious points. The authors give a useful comparison of the virtues and deficiencies of forging stock produced by casting, extrusion, rolling and hot-pressing, and survey an alarming list of possible defects in forgings which have to be inspected for, and, of course, avoided, if satisfactory quality is to be attained.

Surface defects are also a challenge to the wire-drawer, and Miller³⁰ shows how they may originate at the cast wire-bar stage, or indeed in any of the intermediate processes, including heating and rolling. The effects of composition and fabrication history on the electrical conductivity of pure aluminium wire are also discussed.

In addition to the contributions to the Institute of Metals Symposium noted above, there have been a number of articles devoted to one aspect or another of aluminium alloy forgings. The increasing use of such forgings in aircraft, their increasing size, and the arduous nature of their service, present great problems for the metallurgist, and demand a rigorous system of inspection. Murch³¹ has described the methods used, including polishing to reveal defects, chromic acid anodising, special attention to that tender zone, the flash line, and the latest instrument of torture in the billet caster's and forger's purgatory, the ultrasonic flaw detector. The term "large forging" has not yet been defined, but Smith and Crowther³² point out that weight and overall dimensions are both deciding factors, a third group being forgings which, although of relatively modest size and weight, require very powerful forging plant. Their paper is a clear exposition of the technology of producing large forgings of high quality in the high strength aluminium alloys, particularly the aluminium-zinc-magnesium-copper type, and it is encouraging that authors of this standing should state that the resistance to stress corrosion of such alloys is not low, and that in assessing failures due to this cause sight must not be lost of the high stressing to which they are subject in service, and the consequent great effect of any departures from normality such as the presence of stress raisers.

Three other authors, all from the same company but writing separately, have also reviewed development in aluminium forging; they are Peel³³, Richards³⁴ and Daniels³⁵. In common with the writers mentioned above, they stress the importance of collaboration in design, of careful inspection between stages of manufacture, and of the final forging operation. Richards includes some interesting curves relating quenching time to temperature to illustrate the cooling rates of forgings quenched in boiling and cold water. One quite surprising finding is that if an anodised specimen is solution-treated, its cooling curve is much steeper than that of a plain specimen, so that a boiling water quench is as

drastic as a cold water quench of an unanodised forging.

Peel's paper formed part of a journal issue devoted to aluminium technology in honour of the centenary celebrations. Other accounts were provided by Staples³⁶ and by Slater³⁷, the former dealing with rolling and the latter with extrusion. Both make an historical approach, Slater noting that the history of evolution of extrusion presses should not be considered without looking as far back as Archimedes. These papers represent an informative summary of developments in these branches of wrought fabrication, and include expressions of confidence in the continuing future expansion of demand for aluminium extrusions, sheet and strip. Further evidence of this confidence is seen in the installation by a major British Company of two new extrusion presses^{38, 39}, of 5,000 and 3,000 tons capacity, to fortify its capacity for the production of bars, rods, sections and tubes, both as-extruded and heat-treated. Associated equipment included heavy stretchers and melting, billet-heating, and heat-treatment furnaces; the buildings are, of course, sheathed with aluminium, and the electrical installation is of aluminium-cored and sheathed cable.

The production of such cable by the direct extrusion process has aroused much interest recently, following the installation by a large cable company of the necessary hydraulic press. This press uses two billets, which must be of equal temperature to ensure even deformation and complete welding during extrusion. For this purpose a six-lane automatic billet heating furnace has been manufactured, and a description of its operation has been published⁴⁰. A general survey of recent furnace equipment⁴¹ also refers to this furnace, and the six 250 kW end-flow furnaces installed in South Wales for the treatment of aluminium strip in coil; smaller air-circulation furnaces for fabricated components in aluminium are also described. The forty-eight illustrations in this article provide an excellent opportunity to learn how the widely differing requirements of various branches of metallurgical industry have been met by the furnace designer and builder.

When the semi-fabricator delivers his sections, sheet, or other wrought form, his problems are ended, but those of the manufacturer of finished articles begin. Two processes designed to simplify production have recently come out of America, and have been described. "Chem-milling"⁴², as its name suggests, is a method of shaping aluminium by acid, alkaline or electro-chemical solution; many advantages are claimed for it, and some information is given as to its application, but there are no details of the solutions used. Roll-bonding⁴³ produces integral tubing from sheet, and involves the printing of a tube pattern in "stop-off" material, rolling two sheets together to final thickness to give pressure welding of the rest of the sheet area, and expansion of the integral tube by hydraulic pressure while the sandwich is held between platens. This is obviously a particularly suitable means for the manufacture of refrigerator evaporator plates. Another American announcement concerns an aluminium pipe line for oil, made from strip by roll-forming⁴⁴ and welding, the cast aluminium couplers being attached by flaring the tube ends by hand or power tools. It is claimed that installation time is only one-sixth of that required for standard steel pipe.

An interesting account⁴⁵ has been published of the establishment in a "new town" of fresh premises for a well known manufacturer of chemical and dairy equipment, and an impressive list of forming and joining

equipment is illustrated. Samuel Smiles would surely have been delighted to read an article⁴⁶ with the title "They started with £300"; particularly as the story is of constant expansion during a brief period of seven years since the company concerned was founded, and of present manufacturing facilities able to deal with such differing products as lorry bodies, cement silos and diesel engine base frames, all in aluminium alloy.

Joining

The subject of joining aluminium and its alloys continues to attract investigators and authors, and industrial developments are rapid. Many papers and articles have appeared, chiefly concerned with fusion welding, especially by the inert-gas-shielded-arc methods, but soldering has also made important advances recently. Aluminium is no longer the "unsolderable metal", and there are now several well-established soldering procedures. The soft-soldering methods have been reviewed by Watkins⁴⁷, who divides the methods of oxide removal into mechanical, including ultrasonic, and chemical, by the use of a flux. He points out that the chief enemy of the soft-soldered joint is still bi-metallic corrosion, but puts forward methods, including selection of solder composition, joint design, and protection, to mitigate this. An important event in 1955 has been the announcement⁴⁸⁻⁵¹ of two new hard solders for aluminium, that is, solders melting in the 420-510°C range, and used in conjunction with a flux removable by washing the joint in hot water. The joints are claimed to be highly resistant to electrolytic corrosion, and examples are quoted and illustrated of tests supporting this contention.

Before turning to the resistance welding of aluminium and its alloys, note must be taken of work by Storchheim⁵² on the bonding by heat and pressure of aluminium to copper and to zirconium. The author shows how the bond strengths are functions of temperature, pressure and time of treatment, and concludes that, while good bonds may be obtained between aluminium and copper, those between aluminium and zirconium are excellent, and bond strengths may be greater than that of the aluminium itself.

In an excellent brief summary of the present position of welding aluminium and its alloys, Lancaster⁵³ states: "It is by no means easy to obtain consistent spot welds in light alloys spot welding has found relatively little use in the post-war years, even in the aircraft industry". That spot welding continues, however, to attract the technologist is shown by the interesting papers that have appeared on the subject. Roberts^{54, 55} has devoted two papers to spot welding, one summarising recent researches of the British Welding Research Association, and the other concerned exclusively with aluminium alloys, especially clad high strength sheet materials. The conditions necessary for the production of good quality welds are listed, but the main conclusion reached is that the process can be applied with confidence provided that two controlling features are remembered, namely that surface condition must be right, and the welding machine must be of adequate current and electrode force capacity.

Spot welding is still used extensively in at least one American aircraft, as shown by Gain⁵⁶, who gives a detailed description of equipment, techniques and test methods employed in spot welding structures in the KC-97 transport aeroplane. In order to ensure weld quality, test welds are made and macro-sectioned

regularly, and although this increases production costs, spot welding is shown to be appreciably cheaper than riveting. Another method of assessing the quality of spot welds is by radiographic examination, and Gardner and Redwood⁵⁷ have presented an account of the necessary equipment and its use. The interpretation of the radiographs obtained is shown by illustrations of typical defects. In these days of high-speed aircraft, fatigue resistance is vital, and the literature of the past decade on fatigue of spot welds has been reviewed by Walter⁵⁸. One principal conclusion reached is that treatment of welds by high hydrostatic pressure after cooling confers considerable improvement in fatigue resistance. Before leaving spot welding, quick reference must be made to the announcement by Hackman⁵⁹ that consumable-electrode inert-arc spot welding has been developed in the U.S.A.; unfortunately, aluminium is not covered by the paper, since difficulty was experienced in obtaining consistent starting of the weld.

Although inert-gas-shielded methods of welding are the most popular for joining aluminium, metal-arc welding still has its devotees, and has the advantage of low-first-cost of equipment. Pumphrey⁶⁰ has provided a valuable assessment of the position reached by this welding process, and explained the fields of application of the electrodes available. He notes that a truly adequate aluminium-magnesium electrode is still lacking, but holds out hope of the ultimate development of a satisfactory type. The same author⁶¹, in an investigation of the metal-arc welding under restraint of aluminium-magnesium-silicon heat-treatable alloys with aluminium-5% silicon and aluminium-10% silicon electrodes, concludes that if cracking is to be avoided the maximum permissible degree of weld dilution for the electrode is, respectively, 55% and 80%.

In the relatively short period since the introduction of argon-arc welding, much has been learned about the fundamentals of the process, but work on the subject continues. Apps and Milner⁶² have investigated heat flow in welding several metals, including aluminium, and shown that heat input is in two parts, the majority due to the electron current, which is highly localised, and the remainder a proportion of the heat generated in the positive column; this latter is more diffuse, and has a marked effect on the width of the heat-affected zone, but little on the fused zone. In a general discussion of difficulties encountered in the welding of aluminium and its alloys, Lancaster⁶³ also considers heat flow, and notes that while theoretical equations may hold accurately for the welding of mild steel, the effect of latent heat in the case of aluminium may upset the calculations.

Just as it is essential for the user to collaborate at the design stage with the founder or forger, so the increasing use of welded aluminium alloy fabrications is revealing the importance of adjusting design to permit of ease of welding and satisfactory products. Hale⁶⁴ has considered some of the factors involved in designing for inert-gas-shielded-arc welding, including choice of alloy, effect of weld characteristics, notch-effect, and the positioning of welds.

The high strength alloys of aluminium still present considerable problems to the welder. Arthur⁶⁵ has reported on two and a half years' work by an American aircraft company on the fusion welding of a solution-treated aluminium-copper-magnesium alloy, and his paper is a mine of information on all factors affecting weld strength. One point which seems to emerge is that good

weld efficiency is always dependent upon re-heat-treatment. A further report on the work of the former welding research team at the University of Birmingham has been provided by Pumphrey and Moore⁶⁶, concerning aluminium-zinc-magnesium-copper alloys welded both by oxy-acetylene and by argon-arc. Some trouble was experienced due to dirt in the weld pool, but this was reduced by thorough cleaning immediately before welding. The use of special titanium-bearing filler rods had a marked effect in reducing the tendency to weld cracking.

Interest across the Atlantic in aluminium-magnesium alloys continues to increase, particularly in view of the importance of welding in ship construction and other applications. Cook, Channon and Hard⁶⁷ have investigated the properties of welds in aluminium-3½-4½% magnesium alloys, and shown that allowable design stresses are 30-40% higher than with welds in aluminium-magnesium-silicon heat-treatable alloys, and—an interesting point—the notch effect of welds is less with these alloys than with most other commercial aluminium alloys. In the same journal issue, Tenner⁶⁸ reports on the mechanical properties of welds in an aluminium-7% silicon-0.3% magnesium heat-treatable casting alloy; joint efficiencies of 100% were obtained by autogeneous welding followed by heat treatment, and ranged from 50-75% as welded. This fortifies the author in his conclusion that design engineers should consider the assembly of complex shapes from simpler castings, including, if necessary, wrought parts.

Increasing attention is being paid to the development of testing and inspection procedures for welds in aluminium and its alloys. Two hot-cracking tests, principally for use with aluminium-magnesium-silicon alloys, have been described by members of staff of the British Welding Research Association^{69, 70}. In a paper on the testing and inspection of argon-arc welds in aluminium vessels, Bradley⁷¹ illustrates typical defects, and these are so alarming that it is comforting to read his general conclusion that the majority of the vessels fabricated have been successful under arduous operating conditions. The chief defect, according to Bradley, is porosity; Houldcroft and Smith⁷² have evolved a method of classifying and reporting the severity of weld porosity, as observed on microsections, according to size, frequency and distribution, thus establishing a porosity code. In similar vein, Young⁷³ has related the interpretation of radiographs of self-adjusting-arc welds in alloy NP.5/6 (B.S.1477) with tensile test results, to show the effect of various degrees of porosity on tensile efficiency in the weld, and thus establish standard radiographs for reference in quality control inspection.

The extending application of aluminium welding in many industries is shown by the increasing number of accounts appearing of practical experience of making weldments for widely differing purposes. In the same journal issue in which Tait⁷⁴ describes British equipment for automatic self-adjusting-arc welding, there is published a note⁷⁵ on a similar equipment, specially modified for pipe welding, the use of which has made aluminium pipe competitive in cost with steel for high pressure natural gas. It was used in laying a 12-mile stretch of 8½ in. pipe from White Point to La Quinta in Texas. Rotherham⁷⁶ has reviewed the applications of welding in atomic energy plants, including argon-arc welding of aluminium and its alloys. Turning to the aircraft industry, Burton and Gardner⁷⁷ mention that in

each Handley Page Herald are over 100,000 spot welds; they have behind them the company's 15 years experience of this method of welding, covering the production of over 3,500,000 welds, of which nearly $\frac{1}{4}$ have been X-rayed, and 100,000 specimens have been strength-tested. Inert-arc welding is extensively used in the American aircraft industry for several metals, including aluminium and its alloys, as Thompson⁷⁸ has described. Whitehead⁷⁹ refers to the manufacture of a complicated exhaust manifold in aluminium-2% magnesium alloy.

The same process is used for the assembly of building components; window frames are a case in point. Hance⁸⁰ has described how office and house windows in aluminium alloy are made by inert-gas tungsten-arc welding, and Fossen and Holmstock⁸¹ illustrate the production of quite elaborate double glazed church windows. For the Bristol permanent prefabricated buildings, in particular, schools, the windows are made by flash-butt welding⁸².

Perhaps the most spectacular recent developments in welding aluminium alloys have been in ship construction. Tait⁸³ has described the automatic welding of assemblies in shipyards using the self-adjusting-arc process, and Jarman⁸⁴ compares the welding speeds attained by that process and by argon-arc welding, both of which were used in the fabrication of the aluminium alloy superstructure of the Canadian ore-carrier S.S. *Sunrip*. This author⁸⁵ has also described the welding of another superstructure, on a ferry boat plying between Yarmouth, Nova Scotia, and Bar Harbour, Maine. The Cunard liner *Ivernia* has a specially designed funnel⁸⁶ welded up from aluminium-magnesium alloy plate and sections, providing a weight economy of 40%.

Special attention must be paid to the auxiliary T.S.M.Y. *Morag Mhor*, the first all-welded aluminium alloy yacht made in this country. Young⁸⁷ has described the work from keel-laying to launching, not omitting difficulties encountered, and the whole enterprise is a great credit to all concerned with the design and construction. The pictures of the vessel at various stages are of particular interest. An extremely important aspect of welding is its cost, and Young⁸⁸ has analysed the economics of inert-gas-shielded welding of aluminium alloys. His general conclusion is that, despite the need for a new type of argon economiser, the method is not expensive, and for the majority of applications it is quicker and cheaper than riveting.

One factor affecting the cost of welding is the cost of cutting and edge preparation. Babcock⁸⁹ claims that by the use of a consumable-electrode inert-gas equipment, with a steel wire, clean, bright edges may be produced at extremely high speeds in aluminium and its alloys. The development of such a process is highly desirable; it might then be said of argon-shielded cutting and welding, as of Chaucer's Doctor and Apothecary, "Each of hem made other for to winne".

Constitution

One characteristic of investigations into the constitution of alloys is that a considerable volume of work can be reported in brief compass; this is true of Axon's⁹⁰ researches with aluminium-copper-magnesium-silicon alloys, which he has continued. Having determined the 460° C. isothermal for alloys with varying copper and magnesium and 2.0% silicon, he uses this information together with that previously ascertained for other fixed silicon contents to evaluate the form of the aluminium-

rich solid solution field at 460° C. With Bagchi⁹¹, Axon has also reported on the constitution of the ternary aluminium-manganese-copper system, and the quaternary system produced by the addition of silicon. With Hill⁹² he has measured the lattice spacings of the solid solution in the aluminium-magnesium-silicon system, and found a departure from simple additivity which is interpreted as indicating a degree of attractive interaction between solute atoms in the solid solution.

Continuing the work at the Fulmer Research Institute on aluminium-copper alloys with additions of cadmium, indium and tin, Silcock, Heal and Hardy⁹³ have investigated the sequence of structures obtained during age-hardening at elevated temperatures. Silcock⁹⁴ has also examined by monochromatic X-rays the intermediate precipitates formed during the ageing of binary alloys of aluminium with the same three elements.

Although the aluminium-14% manganese alloy is so widely used, much still remains to be learnt about its constitution and metallography. Sperry⁹⁵ has attempted to determine the relationship between the phase diagram and microstructures produced under both equilibrium and non-equilibrium conditions in the commercial material. He concludes that the alloy behaves as though it belonged to the aluminium-manganese-silicon system.

Properties

The ease with which grain-growth can be induced in aluminium and its alloys by application of critical strain, followed by heating, is well-known to works metallurgists, and often presents problems in production. Many research workers, however, find it convenient to be able to prepare single crystals by this means, and so determine many interesting properties untroubled by grain boundaries. Such crystals are usually considered to be more perfect than those grown from the melt, but Kelly and Wei⁹⁶ have compared the two varieties, using super-purity aluminium and X-ray methods, and conclude that the sole difference in perfection is that crystals produced by strain-ageing do not have observable low angle boundaries, while crystals from the melt have such boundaries showing disorientations of 1-20 minutes of arc. Liu and Hibberd⁹⁷ have studied the rolling of a 99.998% aluminium single crystal rod, and shown that it retains its original orientation after over 99% reduction in thickness. Orientations of recrystallised grains formed on annealing are recorded, but a most interesting point is that treatment at 300° C. produced no evidence of recrystallisation, which is remarkable in view of the low annealing temperature of polycrystalline super-purity aluminium. Working with 99.6% pure aluminium, Graham and Maddin⁹⁸ find that recrystallisation nuclei lie preferentially in a very thin surface layer, both in single crystals and in fine-grained polycrystalline metal. This effect is considered to be due to the presence of an oxide layer on the surface at the time of straining, under which dislocations become trapped, thus providing nuclei. Plastic deformation in single crystals has also been investigated by Carlsen and Honeycombe⁹⁹, using an aluminium-34% copper alloy. Samples air-cooled from 535° C. were shown to deform in the same manner as pure metal, but air-cooled and aged samples did not show visible slip, while over-aged material fell between these two extremes. Thompson, Coogan and Rider¹⁰⁰ have determined the shape of the hysteresis loop produced by small slowly alternating stresses on pure aluminium single crystals,

and measured the creep rate and rate of work-hardening produced when the alternation is interrupted. They develop a dislocation model to account for the results observed.

In addition to its value as a convenient material for the research worker, super-purity aluminium has a considerable and increasing field of industrial application. Spillett¹⁰¹ has described the production, properties and applications of the metal, and of a series of alloys based upon it. The principal properties listed are high resistance to corrosion, good ductility, easy workability, high conductivity, good anodising properties and high reflectivity when electro-chemically brightened. The relationship between recovery and recrystallisation in super-purity aluminium has been investigated by Perryman¹⁰², who shows that the perfect sub-grains formed during recovery are not the nuclei for recrystallisation. The same author¹⁰³ has also examined the recrystallisation characteristics of super-purity-based aluminium-magnesium alloys cold worked 20-80%, determining the effect of magnesium on the rate of nucleation and growth.

Interest in the fatigue properties of aluminium alloys has increased considerably as a result of the Comet disaster, and the extensive tests made on a Comet pressure cabin. Bishop¹⁰⁴ has summarised the metallurgical aspects of the findings of the Court of Enquiry, and has rightly emphasised the evidence of an important participant that the dangerous factor was the high level of stress round the points where failure is surmised to have occurred, thus requiring only a mild stress raiser to set off fatigue failure. Another important factor is brought out by Haas¹⁰⁵; the higher strength aluminium alloys have very good proof strengths, but their fatigue resistance has not increased commensurately, and this fact must be uppermost in the mind of the aeronautical engineer when designing his structures. Koziarski¹⁰⁶ looks at aircraft welding design from the fatigue aspect, and admits that welds are inherently notch-producing, while the effect on fatigue properties of the residual stress in a weld is very difficult to assess. He also states that the "old-fashioned reinforcement" that strengthens a weld statically actually weakens it dynamically.

Turning to rather more fundamental investigation of fatigue phenomena, Forsyth and Stubbington have continued the work at the Royal Aircraft Establishment on slip. By fatigue testing pure aluminium and alloys with iron, zinc, magnesium and manganese¹⁰⁷, both at room and sub-zero temperatures, they show that the sub-structures produced by cold work before testing alter the appearance of fatigue-induced deformation. A particularly interesting point is that a self-annealing process was demonstrated in cold-rolled pure aluminium under cyclic stresses. Again testing¹⁰⁸ at various temperatures, this time using solution-treated alloys, they observe the extrusion from slip-bands of crystalline material in the form of a very thin ribbon, which leaves a cavity that represents the initial fatigue crack. These extruded ribbons are cleverly shown in a series of photomicrographs.

Continuing his creep investigations, Wilms¹⁰⁹ has studied the effect of initial sub-structure on the creep of pre-strained aluminium. He describes the creep history involving growth of the sub-structure and attainment of an equilibrium structure, and explains the effect on creep rate.

A number of accounts have been published of investigations aimed at measuring important physical and

mechanical properties of aluminium alloys, either simply to augment knowledge or to support previously formed theory. Thus Polmear and Hardy¹¹⁰ have compared instantaneous apparent specific heat measurements of aluminium-4% copper and aluminium-4% copper-tin alloys, and shown that evolution of heat on precipitation is much more rapid in the presence of tin, thus indicating that precipitation itself is greatly accelerated, and supporting the view that tin facilitates the nucleation process. Hardy¹¹¹ has also reported on the properties of aluminium-copper-cadmium alloys in sheet form, including workability, strength, and resistance to stress corrosion. Two authors have considered the properties of products made from sintered aluminium powder. Doyle¹¹² surveys methods of manufacture and fabrication, and, particularly, the high strength offered at elevated temperatures. He makes comparisons between SAP and titanium, which emphasise the remarkable properties offered by this composite material. Similar information is given by Irmann¹¹³, who proposes a number of applications for wrought and for moulded products in SAP.

Solution of metals in one another is important in alloy manufacture, but it was principally in connection with aluminium brazing that Craighead, Cawthorne and Jaffee¹¹⁴ measured the rate of solution of solid commercial-purity aluminium in molten aluminium-silicon alloys. They demonstrate a linear relationship between time of contact at constant temperature and depth of penetration, and also give curves for optimum silicon contents for minimum solution rates at various temperatures.

One result of the increasing use in aircraft of high strength aluminium-zinc-magnesium-copper alloys has been the greater availability of scrap of this composition, and a casting alloy of the aluminium-5% silicon-3% copper-2% zinc type has been added to B.S.1490 (LM.21) to enable advantage to be taken of this. Before this action was taken, extensive tests were made by the organised refiners and foundries, as reported by Smith¹¹⁵, and by the British Non-Ferrous Metals Research Association¹¹⁶, to ascertain whether zinc contents of the order of 2.0% had any deleterious effects on the properties of the alloy. Smith concludes that additions of zinc as high as 3.0% have no effect on tensile properties and hardness at normal temperatures, nor do they affect age-hardening characteristics. Similarly the B.N.F.M.R.A. show that zinc up to 2.0% has no effect on mechanical properties or on atmospheric corrosion resistance.

Dudzinski¹¹⁷ has investigated the effect of the contents of nitrides of various metals on the Young's modulus of aluminium, and has demonstrated appreciable improvements: the fundamental reasons for this are discussed.

Corrosion and Protection

One of the earliest commercial applications of aluminium was in the chemical engineering industry, especially as containers for strong nitric acid, a purpose for which it is still widely used. Another material in this field is stainless steel, and Willging¹¹⁸ and his collaborators have studied the aluminium/stainless steel couple in fuming nitric acid at temperatures up to 160° F. Aluminium is preferentially attacked, protecting the stainless steel. With separate specimens, increase in rate of acid flow increases attack on aluminium, and decreases it on stainless steel: tentative explanations of these phenomena are put forward. It is established by experience that

when aluminium is immersed in concrete, slight attack occurs during the setting period, but not subsequently, unless the concrete is wet. Wright¹¹⁹ has shown that a case of severe corrosion of aluminium conduit buried in concrete floors was due to the presence of calcium chloride in the concrete mix, aggravated by contact with steel reinforcing bars.

Corrosion of aircraft structures and sheeting is of special concern, in view of the grave dangers attendant upon failures and the longer life nowadays expected from civil airliners. Coburn¹²⁰ has put forward an explanation of the mechanism of corrosion of aluminium by aircraft exhaust gas; he postulates that lead bromide reacts with water giving halogen acid and lead oxide, and subsequently aluminium bromide is formed, which, with water, gives aluminium hydroxide and hydrobromic acid, so that the action is self-propagating. He suggests as a protective coating either epoxy resins or a polyester resin-type tape. The increasing use of aircraft for the spreading of agricultural chemicals, including fertilisers and insecticides, has compelled investigators to seek means of protecting the aircraft structure against these materials. Using laboratory tests, Marshall and Neubauer¹²¹ have studied the effects of fertilisers, and Schreiber¹²² the effects of insecticides, fungicides, herbicides and some fertilisers on several metals, including aluminium and its alloys. They show how the virulence of the compounds varies, and the efficiency of a number of applied finishes. As might be expected, many of the chemicals were highly aggressive, and no finish was successful in resisting them all.

Much has been said during the past few years on the subject of stress corrosion of aluminium alloys, and it is therefore most useful to have an authoritative statement on the subject by Champion¹²³. He wisely begins his paper by making quite clear what he means by the term; the definition is that first published in 1945 by Sutton, Liddiard, Chalmers and Champion. A list is given of the alloys of aluminium not shown to be significantly susceptible to stress corrosion, and of those that do not normally require protection against it; the alloys covered by these lists are the great majority of these in general use today. Some information is given on protective measures for other alloys. Residual stresses inevitably remain in a welded structure, and Parkins¹²⁴ has described how this may lead to stress corrosion in susceptible alloys; he shows photomicrographs of stress-corrosion cracks in stainless steel and in an aluminium-10% magnesium alloy. Methods are discussed of reducing stress corrosion tendency in weldments.

Under severe conditions, aluminium in contact with plain carbon steel can suffer preferential attack. Methods of preventing this include coatings of certain non-ferrous metals on the steel; Britton and Staepoole¹²⁵ have compared the efficiency of zinc, cadmium and tin-zinc alloy, and conclude that the last is the most useful general purpose coating. Working on a more fundamental branch of corrosion science, Aziz and Godard¹²⁶ have assessed the effect on pitting probability of specimen area, using commercial purity aluminium in tap-water. The relationship was found to be linear, thus supporting the authors' contention that pitting sites arise in a random manner, through the interaction of very large numbers of anodic and cathodic elements on the surface.

The centenary celebrations brought out two interesting brief summaries of the finishes used for aluminium, protective and decorative, by Brace¹²⁷ and by Gardam

and Jones¹²⁸. The latter authors devote two paragraphs to the "blackening" phenomena often observed on aluminium holloware in which hard domestic water has been boiled; they relate the latest theory as to its nature, and mention that the colourless films formed in boiling distilled water often have considerable protective values. Sharp¹²⁹ has surveyed the finishes commonly used with domestic appliances, including anodising and stove-enamel finishing for aluminium and its alloys.

The anodising process continues to grow in importance, and Brace¹³⁰ has provided a summary of recent research in America into the nature of the protection afforded by the anodic film, and the variation in properties of films produced in differing electrolytes. Hérenguel, Lelong and Nouaille¹³¹ have published an account of experiments on the anodising of semi-finished products in sintered aluminium (SAP), concluding that, by adjustment of bath conditions, protective films can be produced which are almost as hard as those formed on aluminium metal. An American company is applying a special anodising process to grow thick coatings on aluminium; the account by Dickinson¹³² does not give sufficient detail to enable a confident comparison to be made with hard anodising as understood in this country. The availability in quantity of super-purity-base aluminium alloys has led to much interest in them for exterior trim for vehicles and buildings, and for jewellery, and methods of obtaining an attractive reflective surface include both electrochemical and chemical brightening. Brace¹³³ has reviewed the history and development of the various processes used, and compared the results obtained. Special vitreous enamel frits of low melting point, designed for use with aluminium, have been on the market in the U.S.A. for some years; Biechler and Paulin¹³⁴ have reported on recent tests on various vitreous coatings, including the American formulations, which they consider the most promising.

One of the main points emerging from work over the last ten to twenty years on the painting of metals generally has been the very important improvements in adhesion and paint life resulting from correct treatment before painting. This was early realised by aluminium technologists, and paint systems on aluminium alloys have been shown by experience to have especially long lives. Clark¹³⁵ has carried out systematic tests on painted aluminium alloys in a chemical works, and shown quite clearly that aluminium is much superior to steel as a base for paint, and in areas where steel requires painting annually or oftener, painted aluminium alloys show little deterioration after 4 years. This is an excellent paper—extremely practical in the information it gives.

A great field of application of aluminium is its use in the protection of other metals against corrosion. A third edition has appeared of Edwards and Wray's¹³⁶ standard work on aluminium powder and paint, covering every aspect of these products, including many not well known in this country, for example, the mixing of powder in soap to render it "floating" by the hydrogen resulting from reaction with the alkali present. As the authors have been in the powder and paint field for over 30 years, the information they give is authoritative.

Following the work by the British Iron and Steel Research Association, interest has continued in the protection of steel by hot-dip aluminising, although industrial application has been slow. Hughes¹³⁷ has reviewed the process and possible applications. He mentions the successful anodising and dyeing of coatings,

and also that hot-dip aluminising has been used to protect creep-resisting steels at elevated temperatures. In collaboration with Thomas, Hughes¹³⁸ has also reported tests on the scaling resistance of hot-dip aluminised mild steel. Effective protection is afforded up to 800° C., the weight gains being less than with heat-treated sprayed samples, and small percentages of sulphur dioxide in the furnace atmosphere had little effect. Silicon in the aluminium reduced the scaling resistance.

Spraying with aluminium is much more firmly established than dipping, and Shepard and McWaters¹³⁹ have described the processes used and also given recommendations for coatings for various exposures. As with other workers, these authors seem to prefer zinc for maritime exposure and aluminium in industrial atmospheres. In March, 1955, the Corrosion Group of the Society of Chemical Industry held a symposium on the protection of structural steel, at which papers were read on sprayed metal coatings. Ballard¹⁴⁰ and Rivett¹⁴¹ each reported on extensive practical experience; the former mentions that the continuing success after 6 years of the aluminium sprayed steel above crane level at the Trostre and Abbey Works of the Steel Company of Wales has resulted in the method being applied at Velindre. Rivett makes the interesting statement that for highly aggressive situations, such as railway bridges exposed to locomotive smoke, a composite coat of zinc followed by aluminium is very successful; he has not encountered trouble with blistering. Tremlett and Johnson¹⁴² show that aluminium-sprayed steel presents no serious problems in welding or gas cutting, although cutting is a little slower than with uncoated steel. Ainsworth¹⁴³ has found sprayed metal coatings valuable in a chemical works; for unpainted coatings, he prefers zinc, although aluminium gave good service with a paint coating.

Applications

In an article of manageable length, it is possible only to glance at a few representative accounts of applications of aluminium that have been published during 1955. Handforth¹⁴⁴ summarises the properties of the metal and its alloys attractive to the designer and user, and describes and illustrates examples from many industries of aluminium's versatility. Transport in all its forms is one of the main fields, and road vehicles remain the largest single outlet for aluminium semi-manufactures; indeed, they are the principal materials for body building. It is rather unusual to read of a tipper body¹⁴⁵ made without the use of sections; this has, however, been achieved by using aluminium-magnesium alloy sheet and plate, suitable for flanging, and making all joints by welding. In some aluminium alloy drop-bottom trailer trucks¹⁴⁶, the only mechanical fasteners are the bolts holding the draw bar to the hopper body, the rest being entirely welded up from plate and sections, giving lightness with high corrosion resistance.

The success of the unpainted coaches in aluminium alloy on the London Underground has aroused world-wide interest, and four cars, also unprotected, have been supplied from this country for the Toronto subway¹⁴⁷, opened in the Spring of 1954. This is a good instance of Canadian aluminium, worked and fabricated in England, returning to its country of origin. Diesel trains¹⁴⁸ are to be introduced on a number of branch lines of British Railways and are already running between Leeds and Bradford; extensive use is made of aluminium in the

construction of the cars, underframe and body being entirely in aluminium-magnesium-silicon alloy.

Since the war, much effort has been put into solving the problems involved in the application of aluminium alloys to shipbuilding, and in a fairly detailed statement of the present position, West¹⁴⁹ shows that all the major technical problems have been solved, and that what is now required is more extensive use of the metal by shipbuilders to prove its advantages by practical experience. An account has also appeared of the considerable use of aluminium in shipbuilding in Norway¹⁵⁰, with special reference to the preference in that country for metal-arc welding. Indeed, many authorities feel that it is necessary to use welding to gain the full advantages of aluminium; thus the aluminium alloy superstructure¹⁵¹ of the wood-pulp carrier M.S. *Manicouagon* is entirely fabricated by inert-gas-shielded-arc welding, while a huge lift¹⁵² on an American aircraft carrier is of welded tube construction. It is claimed by the Americans to be the largest all-welded aluminium structure in the world; it weighs 87,000 lb.

A brief mention must be made of a notable symposium held in London on December 7th and 8th, 1955, under the auspices of the Institute of Welding, the British Welding Research Association, the Institution of Naval Architects, the British Shipbuilding Research Association, and the Aluminium Development Association. Twenty-one papers were presented and discussed in four sessions, and attendance was large, including many overseas visitors. The papers and discussions are to be published early in 1956.

In the building field, aluminium is now an accepted material both for structures and other components. Johnson¹⁵³ has stated that the biggest single use of aluminium sheet is for the roofing and cladding of buildings; he describes typical applications and the techniques employed. He mentions the spread, particularly in America, of curtain walling in aluminium; Grindrod¹⁵⁴ has described the manufacture of the 6-ft. and 12-ft. panels for the new Alcoa building in Pittsburgh, which are clad with aluminium-silicon alloy and anodised to a pleasing grey colour.

A new factory has been built for the manufacture of aluminium windows¹⁵⁵, and the methods of fabrication have been summarised, together with examples of window installations. Aluminium glazing bars¹⁵⁶ were used in the re-roofing of a public baths in London, including a glazed area of nearly 6000 sq. ft.; the saving on maintenance of such a large area is obvious.

In Longview, Texas did R. G. Letourneau, Inc., a stately pleasure dome decree, and Lund¹⁵⁷ has shown how it was welded up from aluminium sheets by the shielded-arc process. Its area is 70,000 sq. ft., and it is used for displays, athletic events and the like. The Hungarians have built a bridge in aluminium-copper-magnesium heat-treatable alloy, crossing a drainage canal at Szabadszallas; its building has been described by Bolcskei and Haviar¹⁵⁸.

Developments in the electrical applications of aluminium have been numerous over recent years, so that it is particularly timely to have a clear account of them from Bailey¹⁵⁹, who deals with both technical and economic considerations, and envisages a major changeover to aluminium, in the future, stemming from the high price of competitive materials. One of the most difficult electrical installations ever made was the Kemano-Kitimat transmission line over the Kidilda pass; the

towers were assembled from tubes welded up from sheet in aluminium alloy as described by Grindrod¹⁶⁰.

An interesting aluminium pipe installation is that laid from an offshore well to a shore station in Lake Maracaibo¹⁶¹, Venezuela, aluminium being used because of its resistance to corrosion by the brackish lake water. Bigford¹⁶² has reviewed the uses of aluminium in the oil industry, particularly as pipes, and described welding technique and strength tests on welded lines.

Light equipment is always important for mountaineering or polar expeditions, and an experimental aluminium-alloy sledge¹⁶³ was used by the British Spitzbergen Expedition, 1954. One of its secondary advantages was that it was invaluable as a container for snow which was melted by solar heat for use as drinking water.

Standards

The most important event in standards for aluminium and its alloys has been the issue of the 1955 revisions of B.S.1490¹⁶⁴ covering ingots and castings, and B.S.1470-1477¹⁶⁵ covering the various wrought forms. Elliott¹⁶⁶ has described the changes incorporated in B.S.1490: 1955 including four new alloys and the discontinuance of two old ones. The standards for wrought materials were published at the extreme end of the year, and no doubt assessments of them may be expected to appear in journal articles in the early part of 1956.

Elliott¹⁶⁷ has also reviewed the standards for aluminium and its alloys as they existed before these recent revisions, with glances at standards for fabricated products incorporating aluminium, and some reference to Codes of Practice and international standardisation. With Bigford¹⁶⁸ he has explained the standards for rolled products and discussed how properties can vary according to production conditions. All these papers emphasise that British Standards are prepared by representatives of both supplier and user, and every effort is made to ensure that they represent the agreed views of all concerned.

In parallel with the standards for aluminium and its alloys for general engineering purposes, there is an urgent need for a similar series dealing with the metal for electrical applications. The first of these, for wire, has been published¹⁶⁹, and others are in preparation. Work has continued on additions to B.S.1728¹⁷⁰, referee methods of analysis, and two new sections, on iron and zinc, respectively, have been issued. A second part¹⁷¹ has been added to the standard for sprayed metal coatings; it deals with aluminium coatings for protecting iron and steel against sealing at elevated temperatures.

Last, but of great significance, a standard has been prepared¹⁷² for aluminium alloy sections for shipbuilding, profiles for welding and for riveting being included.

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Trends in the Welding of Aluminium Alloys

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Recently, and particularly during the past year, the emphasis in aluminium welding has shifted away from the development of new processes to the problems involved in their application. In this review, the trends are discussed in relation to spot welding, arc spot welding, shipbuilding, high strength alloys, and cutting.

IN taking stock of the present position regarding the welding of aluminium alloys, the reviewer must look back over the recent history of the subject as presented in the published information. It then becomes apparent that a fundamental, if subtle, change has taken place in the character of the literature, which is a reflection of the state of the industry to-day. In the years just following the war, great strides were made in the development of welding methods, and by 1950 the basic processes for welding in gaseous atmospheres were established. The literature of the time was very much concerned with descriptions of equipment, discussion of principles and laboratory tests, some accounts of commercial applications, and a great deal of speculation as to future possibilities. Recently, and particularly during the past year, the emphasis has shifted away from processes towards the problems involved in their application, and such aspects as design for welding, economics, and inspection. The size and weight of welded aluminium structures continues to increase, and the price of argon for welding has ceased to be a subject to provoke heated discussion. British industry is using American welding processes with a will, and the Americans have discovered the merits, well known in Britain, of the aluminium-magnesium alloys for welding. While no basically new methods for welding aluminium alloys have appeared, interest in processes has been sustained by two ingenious adaptations of existing methods: these will be described later. An indication of the healthy state of development is given by the fact that it was possible to hold conferences on the related subjects of inert-gas arc welding and aluminium and welding in shipbuilding, within a few weeks of each other, and to obtain an active discussion of the 34 papers presented.

In this review trends in aluminium welding are discussed under the headings, spot welding, arc spot welding, shipbuilding, high-strength alloys, and cutting.

Spot Welding

After the war years, in which much interest was displayed in the spot welding of the strong aircraft alloys, there followed what appeared to be a recession of interest in the method. Machine development and research on techniques and design continued, however, so that it is now possible to point to applications which indicate that the process has taken its place among those suitable for the construction of primary structures.

In several large aircraft of British manufacture, spot welding is being used extensively. The fabrication of the Handley Page Herald has been reported in some detail⁽¹⁾. The fuselage of this aircraft contains close on 100,000 spot welds, and the wings more than half this number, mainly in the clad duralumin type alloy D.T.D. 710. It is of particular interest to note the considerations which led to the adoption of spot welding

on such a large scale. These included: cheapness and more reliable service compared with riveting; the superior surface finish with thin gauge sheet; and the ease of inspection. Large scale applications of high quality welding, spot welding or fusion welding, are only successful if due attention is paid to structural design, process and equipment selection, process control, and inspection.

The choice of the equipment or welding machine for a particular application is sometimes difficult, the more so when a new project is begun and it is difficult to foresee future developments. Much attention has been directed in recent years to A.C. machines with facilities for controlling the rate of rise of welding current and its subsequent decay—that is, slope and taper control. Large three-phase machines have also been developed, known as frequency changers, which supply pulses of unsmoothed D.C. These machines have a number of advantages, including a balanced power demand, and are becoming popular for welding the thicker material. The developments in machines and the principles of spot welding light alloys have been reviewed recently^(2,3). Work on process variables and their effect on strength and consistency has been carried out for many years at B.W.R.A. A summary report on this subject, dealing in particular with the high-strength aluminium alloys⁽⁴⁾, has been followed recently by a revised edition of the B.W.R.A. Recommendations on Spot Welding Aluminium Alloys⁽⁵⁾.

High quality spot welding, desirable for aircraft work, demands special attention to surface cleaning to obtain a consistent and reasonably low contact resistance. In automobile manufacture, however, the relatively high resistance of the as-received and degreased surface of certain alloys, particularly aluminium-magnesium alloys, has been utilised to develop heat at the interface and reduce the current necessary for welding. The considerable sacrifice in quality and consistency is accepted, and special production procedures are necessary in the fabrication of the sheet to give a suitable surface finish. These techniques are in use in Britain, but the most spectacular example is the manufacture of the Dyna-Panhard car⁽⁶⁾. This application is of particular interest because of the use of portable gun welders. These were of a special design in which the gun assembly contained the welding transformer—a procedure adopted to reduce losses from secondary leads, such as occur in the conventional equipment for welding steel. The electrodes were operated hydraulically to economise in space and maintain higher pressures than would have been possible with the normal pneumatic gun. Although the gun is larger than the normal type, and slower in use, it is still reasonably portable and is used successfully on this car body, which has been designed to give good accessibility to joints.

Arc Spot Welding

This joining method uses electric arc welding to produce local welds in overlapping sheets and this is the only similarity to electric resistance spot welding. The heat for welding is not generated within the joint by the resistance of the sheet to sheet interface, but is obtained from an electric arc outside one of the two external surfaces of the joint. The method made its appearance some years ago as tungsten-arc spot welding⁽⁷⁾. A special form of inert-gas tungsten-arc torch with a water cooled nozzle is employed. This is pressed against the overlapping sheets and the arc is struck for an automatically timed period, which is sufficient to melt a spot of the outside sheet and fuse it to the underlying sheet. As the method requires access from one side of the joint only, it could have been extremely useful for aluminium alloys, but, unfortunately, the tenacious nature of the oxide film on the aluminium often prevents fusion between the sheets although melting has taken place. This gives low strengths and unreliable results, so that the process is limited to use on stainless steel.

Another variant of arc spot welding of more recent origin uses the inert-gas metal-arc process⁽⁸⁾. This may be called consumable electrode spot welding, and it utilises basically the same equipment as for manual fusion welding. Automatic controls for sequence and timing are added, and a flat-characteristic power source is necessary. When the arc is struck, a weld pool forms and metal is added to this from the wire electrode, which is the positive pole of the arc. Because of the added metal, gaps in fit-up can be bridged and oxide films are more easily broken down. Although not recommended for aluminium alloys at present, the method may be applicable to thicker sheet if the present reported difficulties in starting are overcome.

Terminology

The equipment and processes for inert-gas arc welding continue to develop faster than the standard terminology for its description. An attempt to remedy this situation has been made in the publication of an amendment to B.S.499, the standard glossary of welding terms. There is still some confusion of terms, especially between inert-gas tungsten-arc welding and inert-gas metal-arc welding, (known frequently as argon-arc and Argonaut or Sigma, respectively) which the new standard should help to clarify.

The new standards are helpful in view of the recent use of nitrogen, argon + oxygen, argon + carbon dioxide, and carbon dioxide itself as shielding gases, since they open the way to the use of the unambiguous terms tungsten-arc and self-adjusting arc. The latter process has recently assumed importance in the shipbuilding field, and has helped considerably toward the increased use of aluminium in ships.

Aluminium Welding in Ships

It was in Scandinavia that the first successful application of welding in ship structures of aluminium took place. Coated electrode metal-arc welding was employed. About 1949, certain American yards began fabricating marine structures by welding with the self-adjusting arc process. This process was used for the first time in Britain in 1952 for the welding of a deckhouse on the launch *Queen Elizabeth*, a small project by present standards but an interesting one, because the welding

was done in the open air. Then followed a major undertaking in the welding of the all-aluminium alloy yacht *Morag Mhor*⁽⁹⁾. This vessel has a displacement of 45 tons and was fabricated from aluminium-magnesium alloy, this distinguishing it from vessels of similar size fabricated previously in the U.S.A. from a magnesium-silicide alloy. The general trend is away from the latter alloy for plating, in favour of the aluminium-magnesium alloys. For beams and stiffeners, present practice favours aluminium-magnesium alloys, but the aluminium-magnesium-silicon material is also used. There are several reasons for this preference. The most important being the higher ultimate strength and greater uniformity of the joint, and the ductility of the weld metal in the case of the aluminium-magnesium alloy. The fact that filler metal of basically the same composition as the parent metal can be used is an added advantage. With the aluminium-magnesium-silicon alloy it is necessary to use a high silicon filler metal.

In connection with the trend toward aluminium-magnesium alloys, the fabrication of the superstructure for the *S.S. Sunrip* is of interest, because it represents the first major break away from the use of aluminium-magnesium-silicon alloys for shipbuilding on the North American continent⁽¹⁰⁾. Both tungsten-arc and self-adjusting arc processes were employed, the former for thin gauges and "melt-down" joints.

It has been recognised by those concerned with light alloy welding developments that the large scale application of the new welding methods in shipyards will necessitate special attention to design, fabrication procedure and equipment adaptation. The new inert-gas welding methods utilize costly and relatively complex apparatus, and aluminium alloys require greater care and cleanliness in both preparation and welding than does steel. It is not always that a new process is exploited to the full when first adopted, but such is the case in a British yard, at present building a large liner for Norwegian service, where significant developments have been quietly taking place. A brief report⁽¹¹⁾ indicates that the structural design has been adapted to allow mechanised welding of the stiffeners to large panels of the plating. Inert-gas metal-arc welding using controlled-arc equipment was employed to make both butt and fillet welds. Welds between stiffeners and plating can be extremely small and still fulfil their function satisfactorily. Normal practice employs intermittent welds made manually. With mechanised welding, however, small continuous fillets can be made at high speed, giving a neat appearance and reducing distortion to an extremely low level. In the application reported, some fillet welds of $\frac{3}{16}$ in. and $\frac{1}{2}$ in. leg length were used. When the full story of this application eventually appears, it will undoubtedly demonstrate the potentialities of inert-gas metal-arc welding and show that, properly used, this is the right process for major structural work in shipbuilding.

By strange coincidence, each January issue of *The British Welding Journal* has carried a paper on a new development in the marine application of inert-gas arc welding. The most recent¹² shows how both argon-arc and self-adjusting arc equipment were used to weld thin gauge material in both a hull and a deckhouse. Trouble from distortion was almost eliminated by suitable jiggling and choice of techniques, and it was considered that there was a considerable saving in man-hours, compared with riveting.

The recent symposium, *The Use and Welding of*

Aluminium in Shipbuilding, organised by five co-operating bodies, was an event of some importance. The papers presented, which will be published later, are listed in the bibliography⁽¹³⁾ and cover many aspects of the subject. Those of metallurgical interest included papers on metal-arc welding in Britain and Scandinavia. The metal-arc process poses a number of difficult metallurgical problems, particularly in relation to aluminium-magnesium alloys. These problems have been under investigation, and there has been a steady improvement in British metal-arc electrodes over the past five years. Although the writer of this review considers that inert-gas metal-arc welding is the most suitable process for general use, each method has its rightful place, and an all-position electrode could be useful in the site assembly of pre-fabricated panels, also for repairs and short lengths of weld for which it would be troublesome to move inert-gas arc equipment.

Other papers of metallurgical interest in the symposium are those on the causes of porosity, filler alloy selection, joint strengths, economics, and inspection. Now that large quantities of aluminium alloys are being welded, there has arisen a need for a suitable standard of inspection. Various bodies are considering the subject and a recent paper⁽¹⁴⁾ is of considerable help in this matter. Examples of typical defects encountered in the welding of vessels have been catalogued recently⁽¹⁵⁾.

In addition to the papers on economic aspects included in the symposium on shipbuilding, a recent paper has examined the factors to be considered in estimating the cost of using the inert-gas arc welding methods⁽¹⁶⁾. Important conclusions are that the cost of welding is a small proportion of the total cost of materials and labour. Nevertheless, excessive wastage of argon was revealed, and it is suggested that there is a strong case for a new design of argon economizer.

Welding High-Strength Alloys

Although these heat-treated aluminium alloys are used extensively in the aircraft industry, they are not joined by fusion welding to any appreciable extent. The problem of welding such alloys was thought at one time to be intractable, but research programmes on both sides of the Atlantic have indicated that it should be possible to develop techniques which could be employed successfully. Details of preliminary work in the U.S.A.⁽¹⁷⁾ and in Britain indicate the possibility of reasonable joint efficiencies. Some of the experimental techniques employed in work on these and other alloys being carried out at the B.W.R.A. have been published in the last year. A metallographic method of assessing density and reporting the size and distribution of pores has been used in work on porosity⁽¹⁸⁾. Weld cracking is a particular problem with welding high-strength alloys; an equally important aspect is the strength of the weld metal. The approach has been to find filler materials capable of giving the highest weld metal strength consistent with adequate resistance to cracking in commercial use. In this work, it has been necessary to bear in mind constantly the fact that the composition of the weld metal is the important factor, and that the filler metal analysis is only one means of controlling this. Due to dilution effects^(19, 20), joint design and welding technique can have a very considerable influence on composition. The development of filler alloys has been facilitated by the use of a simple, economical cracking test⁽²¹⁾.

Cutting Methods

Cutting aluminium by thermal methods, such as employed on steel, has never been satisfactory. In the past year, however, American sources have published accounts of two different methods for cutting aluminium, both of which utilize an electric arc. One of them employs a gas shielded self-adjusting arc with an iron filler wire operated at high currents⁽²²⁾. This method was developed in Britain and reported some years ago⁽²³⁾. Both self-adjusting arc and tungsten-arc cutting were the subject of *ad hoc* work at B.W.R.A.⁽²⁴⁾ but, unfortunately, at the time there was neither interest nor money to continue this work. More recently the American development of tungsten-arc cutting with an argon-hydrogen atmosphere promises to provide a useful tool for what has previously been a difficult job⁽²⁵⁾. One might speculate that although the new tungsten-arc cutting employs much the handier tool, the iron wire self-adjusting arc method might be better for preparing bevel edges mechanically.

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New Margam Blast Furnace is Europe's Biggest

ON Tuesday January 10th, 1956, Mr. Harald Peake, Chairman of the Steel Company of Wales, Ltd., performed the lighting-up ceremony which brought into operation the new No. 4 blast furnace at Margam Works. Among those present on this informal occasion were representatives of the engineers, consultants and contractors who have been responsible for building the furnace, as well as those who will now be responsible for its operation.

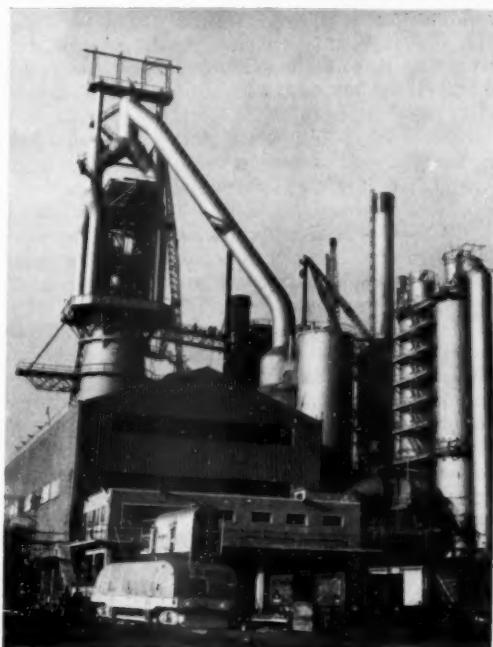
With a hearth diameter of 29 ft. 9 in., the new furnace is the largest blast furnace in Europe and has an iron making capacity in excess of 10,000 tons per week. Because of limitation of space at the site of Nos. 1, 2 and 3 furnaces, it is located on a new site on the south-west side of Margam Works, and is equipped with its own stockyard capable of holding 150,000 tons of ore.

The overall height of the new furnace is 242 ft., and it is similar in construction to Nos. 2 and 3 furnaces, although on a larger scale. In the early days of its construction, considerable difficulties were encountered due to the nature of the substrata. Owing to the predominance of clay in the gravel bed it was difficult to obtain a satisfactory set for the concrete piles. This was overcome by pumping liquid cement into the gravel, after which 445 piles were driven to support the 75 ft. diameter foundation block.

The diameter of 29 ft. 9 in. at the hearth increases to 33 ft. at the bosh, and falls again to 22 ft. 9 in. at the throat. The height of the crucible is 12 ft. 3 in., of the bosh 11 ft. 6 in., of the bosh parallel 8 ft. 6 in., of the stack 58 ft. 3 in., and of the throat 6 ft. 9 in., whilst the height from tuyeres to stockline is 84 ft., and that from hearth to decking 109 ft. 2 in. The working volume (tuyeres to stockline) is 53,975 cu. ft. In all, 1,500 tons of steel and 415,000 bricks have gone into its construction.

Ore from the wharf and from the home ore tippler reaches the new stockyard by overhead conveyor, and distribution of the ore over the yard is achieved by means of a stocking-out bridge. A reclaiming bridge is provided to lift ore from stock and to deposit it on to a conveying system which carries it to the bunkers. A new feature for Margam Works is the scale car track, which differs from that for the other furnaces in that it runs at ground level. This is to facilitate cleaning, and also to enable the car to run direct to the central engineering shop, if and when repairs are necessary. Ninety new coke ovens, which are needed to provide the extra coke required by No. 4 blast furnace were brought into operation a few days before the lighting of the furnace.

Air for the furnace is provided by a 125,000 cu. ft./min. axial-flow turbo-blower—the first steam-driven axial-flow turbo-blower to be used in this country. To preheat the air there are three stoves, each 28 ft. diameter and 140 ft. high, and these, too, are unusual in that the stove control is fully automatic. The stove attendant is able to supervise the sequence of operations from a desk in a control room.



The slag from the furnace will be run into pits alongside the furnace, and from thence it will be loaded by mechanical digging equipment into heavy road vehicles for conveyance to the tips. At the other furnaces the slag is run into ladles for this purpose.

The start-up of the coke ovens and No. 4 blast furnace will ensure that sufficient iron is available when two new open hearth furnaces begin production in the Abbey melting shop during the next few months. This, in turn, will mean that steel will be available to supply hot rolled strip to Velindre Works when that plant comes into operation in the summer.

Molten Metal Pumping Equipment

SHEPPARD & SONS, LTD., announce recent completion of an agreement with The Consolidated Mining and Smelting Company of Canada, Ltd., Trail, B.C., whereby they will manufacture and supply molten metal pumping equipment developed by the latter for the handling of molten zinc. The pump takes the form of a unit submerged into the main body of the metal, and in its present form is capable of a lift of up to 26 in. with a pumping rate of 290 lb. of metal per minute, i.e., in excess of 200 tons in 24 hours. The use of the pump can be extended to other non-ferrous metals, notably aluminium, and enquiries will receive full consideration from the licensees, Sheppard and Sons, Ltd., Bridgend, Glamorgan.

Correspondence

THE SOLIDIFICATION OF CAST IRON

The Editor, METALLURGIA

Sir,

The papers by Mr. W. J. Williams—"The Structure and Mechanical Properties of White Cast Iron" (September, 1955) and "Factors Influencing the Chilling of Cast Iron" (June, 1955)—provide food for thought on the solidification process in general. They confirm the old rule of superheating the metal as far as possible and then pouring it at as low a temperature as possible. But why? It seems safe to assume (and, to my knowledge this has already been demonstrated experimentally) that the melting point—even of a pure metal—is no sharp boundary between the ordered and the fully disordered state, but that the ordering tendency inherent in atoms still persists in the molten state, to be gradually overcome by the disorder forces of thermal movement on the microscopic, and of thermal convection currents on the macroscopic scale; and that, conversely, on cooling a molten metal, the ordering tendency gradually overcomes the disorder forces, assisted by the increasing viscosity, and creates an atomic lattice even before solidification. Figs. 7 and 8 in the first paper seem to confirm this: in the metal cast hot, the structure had time to form, or at least to pre-form, itself at a time when the atoms were moderately free to adjust themselves to the lattice; in the metal cast pasty, the same thing happened in the ladle, but in the process of casting the pre-formed crystalline structure was broken up in the same manner as grains of solid metal are broken up by hot or cold work. After pouring, there was neither sufficient time nor sufficient mobility of the atoms to re-establish order over great domains before solidification took place.

The graphite nuclei theory of Piowarsky made a similar assumption for the graphite atoms—but that was in 1926, at a time when much less was known about atomic structures. Possibly the ordering forces may persist, after melting, to a greater extent in one element than in another: there is also the mutual influence of solvent and solute to be considered. If more were known about this, it would greatly assist in the control of grain size in the "as cast" condition, by the introduction or elimination of substances with strongly persistent ordering forces, which would act as nuclei for the base metal. Preliminary experiments could be made by X-ray diffraction methods on metals and alloys of low melting point, with a view to reaching an understanding of what happens in the technically more interesting metals of higher melting point, which are not easily amenable to this technique.

Yours faithfully

Graz.
Austria

Gunter Erber (Dr.-Ing.)
Maschinenfabrik Andritz

The Editor, METALLURGIA,

Sir,

The work reported in the two papers to which Dr. Erber refers, was carried out with the object of obtaining information which would be of practical value in the production of white and chilled iron castings, and whereas it was fully appreciated at the time that some of the results could be related to concepts associated with the nucleation and mechanism of solidification of eutectic

alloys in particular, this was deliberately avoided in order not to detract from the basic object of the investigations.

Dr. Erber has, however, raised certain points of interest and it may therefore be opportune at this stage to elaborate a little upon some of the more theoretical aspects of the work. Contrary to what Dr. Erber states, it cannot be deduced from the results reported that the work "confirms the old rule of superheating the metal as far as possible and then pouring it at as low a temperature as possible." It has shown that the maximum stability, where graphitizing potential (or chilling properties) is concerned, exists in melts which have not been heated above approximately 1400° C. Once the melt has been superheated to temperatures of the order of 1500° C., this graphitizing potential can only be regenerated by inoculation with graphite. It is true that there is a decrease in depth of chill with decreasing casting temperature, but not to the level of that obtained in melts which have not been superheated.

The experimental work in this respect supports Piowarsky's graphite nuclei theory, and provides an excellent example of the indigenous type of heterogeneous nucleation. Piowarsky extended the graphite nuclei theory to cover the effect of inoculation with ferro-silicon by postulating the development of hyper-eutectic zones resulting in the formation of kish graphite. The present work shows that inoculation with ferro-silicon has a graphitizing effect which is apparent in both superheated and non-superheated melts, thus it eliminates the same depth of chill in each instance, and in this respect differs from inoculation with graphite, which is effective in superheated metal only. It may be that the inoculating effect of ferro-silicon additions is due to the development of sub-microscopic exogenous nuclei.

These comments apply principally to the nucleation of the graphite phase only, which manifests itself as a graphitizing effect reducing the depth of clear chill in the chill test samples.

In the work reported on the mechanical properties of white irons, it was shown that the higher mechanical properties were associated with what was described as a fine grain structure, and the lower mechanical properties with what was described as a coarse grain structure. Discrete eutectic cell boundaries are not observed in white cast irons where the eutectic phases consist of cementite and transformed austenite, due probably to the growth habit of the cementite, particularly when it occurs in the plate-like form. Eutectic cells are more readily seen in grey irons, and Boyles and Lorig* have shown that inoculation with a calcium-silicon alloy (an effect similar to that produced by ferro-silicon) refines the eutectic cell size in grey iron castings. It would be of interest to confirm by similar experimental procedure whether inoculation with graphite also results in a similar grain refinement. Graphite forms one of the phases of the eutectic complex in grey irons, and the presence of graphite nuclei should influence the nucleation of the eutectic cells.

The differences in fracture appearance referred to by Dr. Erber are not due to the eutectic cells, but to the size of the hyper-eutectic carbide plates. These are coarse in the metal cast hot and fine in the metal cast cold. It is thought that the coarse structures are due to the greater temperature gradients set up in the metal cast hot, compared with those in the metal cast cold. A

* Boyles A. and Lorig, C. H. "Notes on the Undercooling of Gray Cast Iron." *American Foundrymen's Association Transactions*, June 1942, 49, (4) 769-788.

similar effect is produced with regard to the primary dendrites in hypo-eutectic irons, although this is not apparent in the fracture appearance of hypo-eutectic white irons. The primary dendrites in hypo-eutectic white irons, and the carbide plates in hyper-eutectic white irons, grow over a temperature range extending to the eutectic temperature, and it is thought that the differences in structure are due to this factor rather than to the theory suggested by Dr. Erber. Whereas it is frequently observed in hyper-eutectic grey irons that the kish graphite flakes are broken due to turbulence in the metal during casting at low temperatures, the differences referred to by Dr. Erber are not due to the fracture of the hyper-eutectic carbide plates. An examination of Figs. 5 and 6 in the paper dealing with the structure of white irons, shows that the carbide plates in the metal cast hot (Fig. 5) are of a completely different order of thickness from the plates in the metal cast cold (Fig. 6), and the difference is not due to the fracture of the former.

A great deal remains to be known about the nucleation and growth habits of the separate phases in white and grey irons, and also about the factors which determine the nucleation and growth of the eutectic cells. Work along the lines suggested by Dr. Erber with regard to

X-ray analysis of melts would be likely to produce valuable information, if the experimental difficulties could be overcome. There are reports in the literature of late additions of solid metal, similar to the melt, having a nucleating effect resulting in a fine grain structure, provided the temperature of the melt does not exceed a limited temperature range above the freezing temperature. In the case of grey cast irons it appears that the temperature range over which the graphite crystal lattices persist is far greater than that which has been found for pure metals, and this is probably due to the fact that the destruction of the graphite lattices is due to their solution in the iron and not because the melting temperature of the graphite has been exceeded, as is the case with pure metals.

These very brief reflections on nucleation have been concerned with heterogeneous nucleation of the indigenous and exogenous variety, but no firm views should be developed in this connection without giving very careful thought to the extremely interesting work relating to homogeneous nucleation, and the effect of interfacial energies, which has appeared in the literature in recent years.

Yours faithfully,
W. G. Williams

Revised British Standard

WROUGHT ALUMINIUM AND ALUMINIUM ALLOYS
(B.S. 1470-77 : 1955) PRICE 6S. EACH (B.S. 1470 : 7s. 6d.)

The British Standards Institution announces the publication of revised editions of the above series of standards, which were first issued between 1948 and 1951. These eight standards deal with various wrought forms as follows :—

- B.S. 1470—Sheet and Strip
- B.S. 1471—Drawn Tube
- B.S. 1472—Forgings and Forging Stock
- B.S. 1473—Rivet, Bolt and Screw Stock for Forging
- B.S. 1474—Extruded Round Tube and Hollow Sections
- B.S. 1475—Wire
- B.S. 1476—Bars, Rods and Sections
- B.S. 1477—Plate

Particular attention is drawn to the fact that the requirements for wire previously covered by B.S. 1474 and B.S. 1475, have been incorporated in one standard, B.S. 1475. This latter standard therefore applies to wire for welding as well as for general purposes : it does not apply to wire for electrical purposes, requirements for which are specified in B.S. 2627. The number 1474 has been allocated to a new standard for extruded round tube and hollow sections, and B.S. 1471 now refers only to drawn tube. B.S. 1472 has been extended to include separate sections for forgings and forging stock, and for stock for forging ; and B.S. 1473 now includes separate sections for stock for small rivets, and for stock for small bolts and screws.

The system of nomenclature adopted throughout all standards in the earlier series has been retained ; but the modifications outlined above have necessitated the introduction of two new prefix symbols, ' V ' for extruded round tube and hollow sections, and ' B ' for bolt and screw stock. The prefix symbol ' W ' is not now used, as the symbol ' G ' is applied to all materials in B.S. 1475.

Three new materials have been introduced in the series, namely super-purity aluminium designated 1, and two aluminium-magnesium-silicon type alloys designated H20 and H30, which have been included immediately following H10 because of their similarity to that material. Alloy H20 contains an addition of copper, and also manganese, and/or chromium, while H30 is a copper-free alloy with an obligatory manganese content. Some amendment has also been made to the composition limits of the other alloys in the series, and in certain cases composition limits and mechanical properties have been rounded in accordance with B.S. 1957 ' Presentation of Numerical Values (Fineness of Expression ; Rounding of Numbers) '.

Other modifications are the introduction of two new conditions, one applying to rivet, bolt and screw stock, the second to wire; the extension to wrought materials of a condition previously applicable only to castings; and changes in the particular alloys and conditions specified for each wrought form. The tolerance tables in several of the series have been extended, and minor amendments made to the values specified.

Copies of these standards may be obtained from the British Standards Institution, Sales Branch, 2, Park Street, London. W.1.

Laboratory Contracts

Baird & Tatlock (London), Ltd., announce that they have recently received the following contracts for laboratory installations : Northern Region Production Development Board, Kaduna, Nigeria—value £2,400 ; Veterinary Laboratories, Astrida, Belgian Congo—value £5,000 ; The Laboratories of Thorium Ltd., Ilford, Essex—value £13,000 ; and The Laboratories of the Castle Donnington Power Station, Leicestershire—value £3,000.

NEWS AND ANNOUNCEMENTS

Structural Aluminium Research Scholarship

THE Institution of Structural Engineers accepted, in 1954, an offer by the Aluminium Development Association of a research scholarship to the value of £400 a year to enable the holder to undertake research on some aspect of the application of aluminium alloys to structures. The scholarship is awarded in alternate years for a two-year period, and the first holder is nearing the end of his tenure. It is the intention of the Institution to make the next award in 1956, with a view to the successful applicant commencing his investigations at the beginning of the university session in October next. Entries for the scholarship to be awarded this year close on March 31st, 1956. The scholarship is administered by the Institution and further particulars, together with forms of entry, should be obtained from the Secretary of the Institution of Structural Engineers, 11 Upper Belgrave Street, London, S.W.1.

Mond Nickel Fellowships

THE Mond Nickel Fellowships Committee now invites applications for the award of Mond Nickel Fellowships for 1956. The main object of these Fellowships is to enable selected applicants, of British nationality and educated to University degree or equivalent standard, to obtain additional training and wider experience in industrial establishments, at home or abroad, so that, if they are subsequently employed in executive or administrative positions in the British metallurgical industries, they will be better qualified to appreciate the technological significance of research and to apply its results. There are no age limits, though awards will seldom be made to persons over 35 years of age. Each Fellowship will occupy one full working year, and it is hoped to award five Fellowships each year of an approximate value of £900 to £1,200 each.

Applicants will be required to define the programme of training in respect of which they are applying for an award, as well as particulars of their education, qualifications and previous career. Full particulars and forms of application can be obtained from: The Secretary, Mond Nickel Fellowships Committee, 4, Grosvenor Gardens, London, S.W.1. Completed application forms will be required to reach the Secretary of the Committee not later than 1st June 1956.

Institute of Metals Medals

THE Council of the Institute of Metals has announced the following awards of medals:—

The Institute of Metals Medal in Platinum for 1956 to PROFESSOR GEORGES LEON CHAUDRON, Doct. ès Sc., Membre de l'Académie des Sciences (Professeur à la Sorbonne: Directeur du Laboratoire de Vitry du Centre National de la Recherche Scientifique), in recognition of his outstanding contributions to knowledge, particularly in the field of the light metals, which have greatly benefited the metal industries.

The Rosenhain Medal for 1956 to DR. DONALD McLEAN

(Principal Scientific Officer, Metallurgy Division, National Physical Laboratory, Teddington) in recognition of his outstanding contributions to knowledge in the field of physical metallurgy.

The W. H. A. Robertson Medal for 1955 and Premium of Fifty Guineas to MR. E. J. THACKWELL (Northern Aluminium Co., Ltd., Rogerstone) for a paper on "The Choice and Construction of Monolithic Linings for Twin-Bath Induction Furnaces for Melting Aluminium Alloys".

Welding Design Course in Cardiff

A FURTHER course on the "Design of Welded Structures" is to be held in Cardiff following a very successful course held there last year. It will commence on the 14th March, 1956, at British Oxygen Gases, Ltd., Birchgrove Works, Cardiff, and the lectures will be held on Wednesday and Thursday evenings from 5.0 p.m. to 6.30 p.m. over a period of six weeks. The course is arranged to assist designers and draughtsmen of welded structures and fabrications, and the lectures will be given by members of Quasi-Arc technical staff. On the final evening the guest speaker will be Mr. A. V. R. Hooker of Messrs. W. S. Atkins & Partners. Further details along with the enrolment form can be obtained on application to the Constructional Design Department, Quasi-Arc, Ltd., Bilston, Staffs.

1956 International Light Metals Convention

ON June 7th to 9th, inclusive, the Third International Light Metals Convention will be held at the Montanistische Hochschule at Leoben, Austria. As was the case at previous conventions in 1934 and 1948, a review will be presented of the present state of light metals development. Lectures will be given by leading experts from Europe, Canada and the U.S.A., and will cover the following fields: light metals in the national and world economy; metallurgy of the light metals (aluminium, magnesium and titanium); technology of the light metals; metallography and physics of the light metals; and development of the light metals.

A detailed programme will be published shortly, and further information may be obtained from the Committee of the Third International Light Metals Convention, Leoben/Stmk., Austria, Montanistische Hochschule, Institut fuer Metalkunde.

International Mechanical Engineering Congress

THE SIXTH INTERNATIONAL MECHANICAL ENGINEERING CONGRESS will be held in Paris from June 4th to 9th, 1956. The theme of this year's meeting is "Surface Treatment for the Improvement of Mechanical Properties and Protection Against Corrosion", and in order to facilitate discussion the theme has been divided into eight sections corresponding to eight working sessions of the Congress. The topics covered will include improvement of resistance to wear by increase of surface hardness and by improvement of friction characteristics; improve-

ment of resistance to heat; improvement of resistance to corrosion by non-metallic coatings, chemical processes, electroplating processes, and metal coatings deposited by means other than electroplating; and surface treatment for decoration and for improving optical properties. Copies of the advance programme and further information can be obtained from The British Engineers' Association, 32, Victoria Street, London, S.W.1., which is the U.K. sponsor of the Congress.

Copper Pass Awards

THE Adjudicating Committee, representing the Councils of the Institution of Mining and Metallurgy and of the Institute of Metals, have made the following Copper Pass Awards in respect of papers published in the *Transactions of the Institution of Mining and Metallurgy* and the *Journal of the Institute of Metals* for the year 1954:—

£100—MR. G. LAWRIE FAIRS, for a paper on "A Method of Predicting the Performance of Commercial Mills in the Fine Grinding of Brittle Materials".

£100—MR. F. KING and DR. A. N. TURNER, for a paper on "The Control of Quality in the Hot and Cold Rolling of Aluminium and Aluminium Alloys".

£50—MR. G. L. HOPKIN, MRS. J. E. JONES, MR. A. R. MOSS and MR. D. O. PICKMAN, for a paper on "The Arc Melting of Metals and its Application to the Casting of Molybdenum".

£50—PROFESSOR M. REY, for a paper on "Flotation of Oxidized Ores of Lead, Copper and Zinc".

The Copper Pass Awards are made from a fund placed at the disposal of the Councils of the two Societies by the Directors of Copper Pass and Son, Ltd., for the encouragement of the publication of scientific and technical papers dealing with processes and plant used in extraction metallurgy and on the subject of assaying, and of papers on processes used in all branches of the non-ferrous metal industry.

History of Metallography

PROFESSOR CYRIL S. SMITH, Sc.D., of the University of Chicago, will deliver a lecture before the Institute of Metals on "The Beginnings of Metallography". The meeting will be held at 4 Grosvenor Gardens, London, S.W.1, on Wednesday, 25th April, at 6.45 p.m. Visitors will be welcome; tickets are not required.

Non-Ferrous Club

THE Annual General Meeting of the Non-Ferrous Club has been fixed for Wednesday, 14th March, at the Queen's Hotel, Birmingham. The main business of the meeting, which will be preceded by dinner, is the election of officers for the coming year.

Change of Address

THE North-West England and North Midlands Office of Wild-Barfield Electric Furnaces, Ltd., is now at 1, Clarkhouse Road, Sheffield (Tel: Sheffield 62784).

Trade Relations Committee

THE first meeting of the Trade Relations Committee of the Council of Association between the United Kingdom Government and the High Authority of the European Coal and Steel Community took place in London on January 9th, 1956. The Committee had an exchange of views on conditions of trade in coal and steel between

the United Kingdom and the European Coal and Steel Community and fixed its further programme of work. The Committee will hold its next session in Luxembourg on April 10th, or earlier if necessary.

Personal News

MR. S. F. DERBYSHIRE has retired from his position as General Production Manager to The British Aluminium Co., Ltd. He will remain in a consultative capacity to the Company for the time being. MR. W. B. C. PERRY-COSTE and MR. J. SALTER have been appointed Joint General Production Managers. MR. P. T. ENSOR has been appointed General Manager of the Canadian British Aluminium Co., Ltd., at Baie Comeau, and MR. A. R. WYLIE has relinquished his post at the Lochaber Works on becoming Works Manager Designate for the Baie Comeau project.

MR. G. R. MARSH has relinquished his position as Managing Director of Wickman, Ltd., but will remain a Director of the Company. He is succeeded as Managing Director by MR. E. A. HYDE, and MR. W. V. HODGSON has been appointed Deputy Managing Director. MR. C. F. WATTS is now Financial Controller, and MR. H. B. MORRIS Secretary of the Company.

MR. L. H. S. HALLING, Sales Manager of A.P.V.—Paramount, Ltd., has been appointed to the Board of Directors.

FOLLOWING the death of MR. A. MYCOE, Metropolitan-Vickers Electrical Co., Ltd., has appointed MR. J. C. ANDERSON to be Traffic Manager.

MR. D. P. C. NEAVE, Vice-Chairman of the Consolidated Zinc Corporation, Ltd., has been elected Chairman of the Zinc Development Association. The former Chairman, MR. W. MURE, Managing Director of the British Metal Corporation, Ltd., will continue as a member of Council.

MR. C. M. SLOCOMBE has been elected to the Board of Samuel Fox & Co., Ltd. MR. A. C. BRIERLEY of the Export Department of United Steel Cos., Ltd., has been appointed to succeed MR. J. H. GOODLAD as Light Steel Sales Manager.

MR. R. H. ATKINSON has retired from his position as Head of the Platinum Metals Section of the International Nickel Co.'s Research Laboratory at Bayonne, New Jersey, after more than 30 years' service with The Mond Nickel Co., Ltd., in the United Kingdom and its Inco affiliates in the United States and Canada.

MR. J. H. BROWN has retired from the Board of Sanderson Brothers and Newbould, Ltd., of which he has been a member for 25 years and Chairman since 1938. MR. J. R. A. BULL, Managing Director since 1952, has been appointed Chairman and Managing Director.

MR. G. HUNT, who has been a member of the Board of Directors of High Duty Alloys, Ltd., since 1951, has been appointed General Manager of the Company.

MR. F. B. HOWARD-WHITE has been appointed a member of the Mond Delegate Board. Mr. Howard-White was appointed Joint Secretary of the Company in 1938, and in May of this year he was appointed a Director of Henry Wiggin & Co., Ltd.

MR. C. J. BRYANT, Secretary of the Bryan Donkin Co., Ltd., and British Furnaces, Ltd., for the past 5½ years, has retired at the age of 72. He is succeeded by Mr. E. ARNOLD.

RUBERY, OWEN & CO., LTD., announce the appointment of Mr. P. S. WALKINS, formerly Librarian at British Overseas Airways, to the position of Librarian and Information officer in charge of The Owen Organisation Library and Information Service, which is part of the Research and Development Department at Darlaston, South Staffs.

Mr. T. O'NEILL has joined The Solartron Electronic Group, Ltd., as Personal Assistant to Mr. E. E. JONES, the Group's Commercial Director.

Mr. G. L. HARRISON has taken up a post as Development Metallurgist in the London Section of the Development and Research Department of The Mond Nickel Co., Ltd., and Mr. P. D. WILMOT is now a Development Chemist in the Department. Mr. J. H. GITTUS, formerly with the British Cast Iron Research Association, has been appointed Section Leader of the Cast Iron Section of the Development and Research Department Laboratory in Birmingham.

PROFESSOR G. B. B. M. SUTHERLAND, F.R.S., Professor of Physics and Director of the Biophysics Research Centre in the University of Michigan, has been appointed Director of the National Physical Laboratory. He will take up the appointment in September.

Mr. J. E. C. BAILEY, Chairman of the Baird & Tatlock Group of Companies, is at present on a visit to Africa.

Mr. T. S. KILPATRICK has relinquished his duties as Commercial Manager of Distington Engineering Co., Ltd., on his appointment as Deputy General Manager of the Workington Iron and Steel Co. He will remain a Director of the Distington Company. Mr. A. E. BELL has been appointed General Sales Manager, and Mr. T. WINTRUP, Contracts Manager, has been appointed Sales Manager (Engineering).

Mr. E. R. PERRY, D.F.C., has been appointed a Development Officer in the Platinum Metals Division of the Development and Research Department of The Mond Nickel Co., Ltd.

Mr. D. COLLINS, Personnel Manager of Geo. Salter & Co., Ltd., has been appointed Chairman of West Bromwich magistrates.

PROFESSOR H. W. MELVILLE, F.R.S., Mason Professor of Chemistry in the University of Birmingham, will take up the appointment of Secretary to the Committee of the Privy Council for Scientific and Industrial Research, in August. He succeeds SIR BEN LOCKSPEISER, K.C.B., F.R.S., who retires from the post on the 10th March, on reaching retiring age.

DELAPENA & SON, LTD., makers of precision honing equipment and induction heating equipment, have appointed Mr. E. D. DIGBY as Area Manager for Scotland and Ireland.

Mr. W. GEARY has relinquished his responsibilities as Works Manager (Services) of the Appleby-Frodingham Steel Co., to take over special duties for the General Works Manager in connection with management studies and statistics. He is succeeded by Mr. T. P. LLOYD, Works Manager (Steel). Mr. W. JACKSON, Melting Shops Manager, becomes Works Manager (Steel).

Mr. S. M. AISENSTEIN has retired from the position of General Manager of the English Electric Valve Co., Chelmsford. He is succeeded by his deputy, Mr. A. J. YOUNG.

Mr. K. J. DOWELL has joined the Technical Sales Department of Smiths Aircraft Instruments, Ltd., as Senior Sales Representative dealing with automatic pilots, flight systems and radio navigation instrumentation.

EDGAR ALLEN & CO., LTD., have announced the appointment as Technical Representative for engineers' tools and tool steels for Lancashire, Cheshire, Westmorland and Cumberland, of Mr. E. D. EASTBURN. A similar appointment for the Midlands and Lincolnshire is that of Mr. L. J. ETHERIDGE. A change in representation is announced for Australia and the Far East, where Mr. J. L. LEE is to succeed Mr. A. P. T. TAYLOR-GILL as special representative of Edgar Allen & Co., Ltd., attached to Messrs. Noyes (Australia) Proprietary, Ltd.

Mr. H. E. HILL, Chairman of Birfield Industries, Ltd., and Laycock Engineering, Ltd., has joined the Board of Darwins, Ltd., and Subsidiary Companies.

Mr. G. E. RICHARDS, Branch Manager of The Morgan Crucible Co., Ltd., in Birmingham, will retire at the end of March after 40 years' service. He will be succeeded by Mr. D. SCOTT, Deputy Branch Manager for the last 2 years.

Mr. W. MOODY has retired after 32 years' service as Managing Director of The Lancashire Wire Co., Ltd., retaining his position on the Board as Vice-Chairman. Mr. A. R. MOODY and Mr. G. W. MOODY have been appointed Joint Managing Directors.

As a further preliminary step towards the restoration of the Steel Company of Wales, Ltd., to private enterprise, it has been decided that the Company will, in due course, set up its own independent Sales Organisation. The Hon. MICHAEL LAYTON has accordingly been appointed Sales Controller of the Steel Company of Wales, Ltd. R.T.S.C. Homes Sales, Ltd., and R.T.S.C. Exports, Ltd., will continue to handle the Company's sales until further notice.

Mr. H. H. ENGLAND has been appointed Manager of the Templeborough Melting Shop of Steel, Peech and Tozer, in succession to the late Mr. S. W. PEARSON. Mr. R. S. HOWES has been appointed Manager, Rotherham Melting Shop, and Mr. D. I. GIBBS, Assistant Manager, Templeborough Melting Shop.

Obituary

We regret to record the deaths of the following:

Mr. GEORGE LEVY, Vice-Chairman since 1928 of George Cohen, Sons & Co., Ltd., who died on 20th December, 1955, at the age of 71. For many years he played a very active part in the development and administration of the George Cohen organisation. Only recently he resigned his Chairmanship of K & L Steelfounders & Engineers, Ltd., of Letchworth—a company acquired by the '600' Group in 1928. It was largely due to his courage and brilliant business ability that the firm was able to weather the economic storms of the great depression of 1929/32, and so, in the course of years, to attain its present industrial eminence as one of the biggest manufacturers of steel castings and mobile cranes in Great Britain.

Mr. HAROLD A. TIPPETTS, Chairman and Joint Managing Director of L. H. Newton & Co., Ltd., who died on 24th January, 1956, after a long illness.

Mr. S. J. MATTHEWS, Head of the Research and Development Division of Baird & Tatlock (London) Ltd., who died suddenly in his office on Monday, 2nd January, 1956.

RECENT DEVELOPMENTS

MATERIALS : PROCESSES : EQUIPMENT

Metal Cleaning By Agidip

MASS-PRODUCTION metal cleaning is of great importance in many industries where the removal of polishing and buffing compounds, swarf, shop dirt, lubricating oils, etc., from metal surfaces is an essential prerequisite to enamelling, electroplating, phosphating, painting or inspection. The di-phase processes originally introduced in the United States were designed to overcome some of the difficulties associated with vapour cleaners, since they employed two different and immiscible liquid cleaners which made contact with the work virtually simultaneously, either by dipping or spraying. These cleaners are becoming widely used in the automobile, engineering and appliance industries, and have the advantages of being non-toxic, rust-inhibiting, and together are capable of removing every type of soil from the metal surfaces to be cleaned. They also offer notable operating economies over trichlorethylene, and being used in concentrations of only 3-5% require no elaborate recovery process. They are equally suitable for ferrous and non-ferrous metals, including zinc, aluminium and magnesium.

A great improvement in the method of application of the di-phase cleaners has recently become possible by the development of the range of Efco Agidip machines, which are specially applicable to the batch cleaning treatment of small intricate components. These machines are pneumatically operated, using the normal factory air line as a source of compressed air at 80 lb./sq. in. No elaborate installation is required, and the machines are portable. Heat is provided by two thermostatically controlled 3 kW immersion heaters fitted in the base of the tank, which is lagged to reduce heat losses.

The Agidip action consists in a regular and rapid up-and-down movement of the work container through two layers of di-phase solutions, causing the items in the easily removable work container to receive a thorough and penetrating dip in each phase in turn on each upward and downward movement. This action results in a thorough cleansing of both oil- and water-soluble soils from the metal surfaces of the work.

The machines are of two sizes, dealing with either 20 lb. or 65 lb. per load. The cleaning cycle takes approx-

imately two minutes, so that the potential hourly output is 5 cwt. or 16 cwt., respectively. The larger machine can handle such items as cylinder blocks and, therefore, should be of particular interest to the automobile and garage industries.

After cleaning in the Agidip, the work may be dried at once by an air blow-off, or, better, passed in a drying cycle through the Agidrier machine, in which a current of hot air is fanned through the work as it moves up and down in an action similar to that of the Agidip.

Electro-Chemical Engineering Co., Ltd., Queens Road, Weybridge, Surrey.

Press Feed Equipment

A recent advance in power press feeding equipment is shown in the accompanying illustrations. Developed and patented by Press Equipment Co., Ltd., the heavier machine was recently installed in the Erdington factory of Messrs. Fisher and Ludlow, Ltd.; it uncoils, straightens and feeds mild steel strip up to 12 in. wide by 0.124 in. thick direct to progressive tools. Feeding up to 60 ft. of material per minute, the machine is capable of accurately feeding material in sequence with the stroking of the press with the clutch permanently engaged. This is achieved by inducing the straightened strip into a bow between a stop in the tools and the output rolls of the machine. As the final progression of the tools takes place, and the component is ejected, the material (which has not been bowed beyond its elastic limit) flows to the end stop for the next stroke. A detector device on the bow engages a hydraulic clutch and re-forms the bow. In practice, this train of events is continuous, and the detector device operates a hydraulic speed variator when running continuously, disengaging the clutch only when the press is stopped.

For long pitch feeding (i.e., cutting to lengths) where the pitch required cannot be traversed through the tools during the daylight with the press running continuously, the bow detection device is arranged to operate as illustrated in the second photograph. In this set-up, the straightened material is fed along a run out table and



through the tools to an end stop. A bow is then induced and detected, de-clutching the feed and engaging the press clutch synchronously. The component is ejected, the bow released and the process automatically repeated. Since in both cases the material itself is the medium of control, accuracy of feed is an inherent feature of this equipment, and infinitely variable feed speeds and lengths are available. Unlike any other roll feed device, the equipment is not tied to any one press, giving extreme versatility. The present range available is from $\frac{3}{4}$ in. up to 18 in. wide, in thickness up to 8 s.w.g., and larger sizes are being developed.

Press Equipment, Co., Ltd., 76-78, Hunters Vale, Birmingham, 19.

Electronic Temperature Indicating Controller

THIS instrument, the latest in the Foster range, has been designed to provide a simple, reliable and inexpensive control system for most industrial processes, and for many laboratory and research projects which may require a fine degree of temperature control. It is suitable for use in conjunction with electrical resistance thermometers, thermocouples, or radiation receiving tubes, so that, by the use of the appropriate sensitive elements, temperature ranges from -200°C. up to $2,000^{\circ}\text{C.}$ may be controlled.



The standard "Resilia" moving coil system is used, with the addition of a light metallic vane attached to the indicating pointer. As the position of the pointer approaches the pre-set temperature, the vane passes between two fixed metallic plates mounted on an adjustable arm, this being set to the required temperature. The movable vane and the two fixed plates form a capacitor, the value increasing from minimum to maximum as the pointer approaches the control setting. This capacitor forms part of an oscillatory circuit which is connected to a trigger circuit controlling a relay which, in turn, is connected to a final relay used to control the energy input to the plant.

Foster Instrument Co., Ltd., Letchworth, Herts.

New Sanding Attachment

SUBSTANTIAL savings in time and labour costs, during the finishing of castings, pressings, dies, fabricated metalwork and other similar components in ferrous and non-ferrous metals, are claimed with a new belt sanding attachment introduced by Wolf Electric Tools, Ltd. Of robust construction, the attachment has been designed for use in conjunction with the 6 in. High Speed Wolf Heavy Duty Grinder, Type GQ6, which



enables the 2 in. wide by 2 ft. long, endless abrasive belt to operate at a light load at 6,000 ft./min.

The attachment consists of a patented 4 in. diameter by 2 in. wide rubber tyred contact wheel, and a cast aluminium bracket at the end of which is mounted a steel pulley running on a ball bearing. The abrasive belt is mounted on the steel pulley and is correctly tensioned by means of a spring loaded eccentric, the assembly position being controlled by an adjusting screw. The attachment bracket is mounted on the end of the GQ6 grinder gearbox in place of the existing wheel guard, and uses the same fixing screws, the rubber tyred contact wheel being fitted on the grinder spindle. This wheel provides a firm but resilient backing for the abrasive belt, and can be used in a similar manner to back stand idlers on bench machines. The slack part of the belt between the contact wheel and pulley makes the attachment extremely suitable for the finishing of convex and concave surfaces. In addition, it is suitable for use on thin gauge material, and for the finishing of stainless steel components, giving polish marks running in one direction only. As the attachment is light in weight, excellently balanced and free from vibration in operation, maximum efficiency with the minimum of operator fatigue is ensured. A selection of abrasive belts is available, all of which are suitable for use on materials ranging from cast iron to wood.

Wolf Electric Tools, Ltd., Pioneer Works, Hanger Lane, London W.5.

Reclaiming Slipper Brasses

QUASI-ARC, LTD., Bilston, Staffordshire, announce that slipper brasses, the bearings contained in drive spindle universal joints of rolling mills, are being built-up at less than two-thirds the original cost by using Sigma welding. These giant bearings, weighing up to 700 lb. each, were formerly sold for scrap when worn, since surface distortion was excessive in previous attempts to reclaim them by build-up. When Sigma welding was adopted for the work, distortion was reduced to a minimum, and the operation was accelerated and made more efficient. These slipper brasses are bronze castings: they are built-up $\frac{1}{2}$ in. with aluminium bronze wire and machine finished.

LABORATORY METHODS

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INSTRUMENTS AND MATERIALS

FEBRUARY, 1956

Vol. LIII, No. 316

Liquid-Liquid Extraction Procedures in Inorganic Analysis

A Review of Practical Applications with Particular Reference to Metallurgical Analysis

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The growing complexity of modern materials has led to difficulties in their chemical analysis resulting from the increasing multiplicity of other substances accompanying the constituent to be determined. The development of new separation methods has made possible the continued use of classical analytical procedures in the face of increasing competition from physical methods, and in the present series of articles the author surveys liquid-liquid solvent extraction techniques in inorganic analysis, with particular reference to metallurgical analysis. In the first of the series, a general introduction to the subject is followed by a discussion of the extraction of Group I metals.

THE materials in use today are almost invariably more complex than those of some years ago. As the complexity increases, the problem facing the analytical control laboratory becomes more difficult, and eventually the stage is reached where time-honoured classical procedures of analysing a particular sample or product have to be abandoned. The reason for the failure of these methods is generally not hard to seek; the tools, instruments, and technique of today are at least as good as, or better than, those of previous years, but the chemistry of the classical methods can no longer cope with the ever increasing multiplicity of other substances accompanying the constituent to be determined. Very often the structural performance demanded from, e.g., an alloy, is obtained by the addition of a trace constituent of one of the less familiar elements *A*. This process frequently ends up with the inclusion of closely related elements *B*, *C*, and *D* in the alloy in order to achieve a slightly better performance. The complications thereby introduced in the analytical chemistry are usually sufficient to invalidate the method previously used to determine *A*. Faced with this problem and the ever increasing demand for quick results, the analyst turns most often to the push-button instrumentation type of analysis. Whilst no decrying this modern trend towards physical methods of analysis, it should be stressed that along more 'chemical' lines necessity has, as always, been the mother of invention, and separation methods have been evolved which enable the classical procedures still to be applied. An examination of developments in analytical chemistry during the past few decades reveals an increase in the popularity of such methods as chromatography, ion-exchange and distribution procedures. These techniques are capable of effecting rapid and quantitative separations of materials which possess very similar chemical properties. They may be used to

remove extraneous material, or they may be used to concentrate the constituent being analysed. In this way it becomes possible to apply the conventional analytical methods, frequently with improved results because of the purification or concentration of the required ion.

It is fairly true to say that until recently the development of these separation methods has been almost entirely the concern of the organic chemist and the biochemist, but recent trends in the inorganic field have shown that their adaption to inorganic analysis is becoming more common. In the present article, it is not the author's intention to review the entire field of liquid-liquid solvent extraction in inorganic analysis. Such a procedure would indeed be virtually impossible, for the titles of many papers give no clue to the presence of a solvent extraction procedure within the text.

The removal of a trace constituent from aqueous solution by means of immiscible solvent extraction is frequently the easiest and most efficient way of separating it from large amounts of other materials. Even if a 100% separation does not occur, the concentration and purification achieved are invaluable. This constitutes what is known as 'extraction for removal'. Where a mixture of substances, e.g., rare earths, is extracted from indifferent materials, the process is referred to as 'extraction for fractionation'. In other cases it is preferable to remove the indifferent material, e.g., iron in steel analysis, in order to get at the minor constituents, which remain in the aqueous solution or raffinate. The exponents of extraction frequently stress that the method circumvents such features as the co-precipitation found in separation methods involving precipitation of a solid phase from solution, but it is true to say that co-extraction can also occur, although it must be conceded that it is much less frequently found.

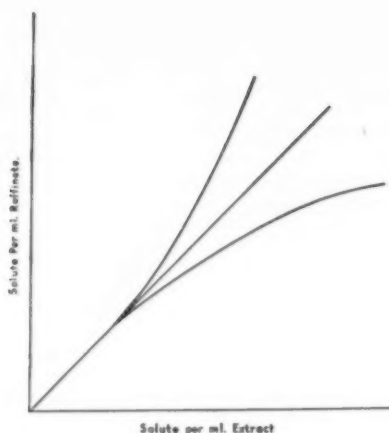


Fig. 1.

Considerations Involved in Applying an Extraction Procedure

The first consideration involved is the choice of a suitable immiscible solvent. Where a favourable one is available, the operation is simplified and simple apparatus is sufficient. Unfortunately, one cannot predict the extractability of a solute from a crude mixture by reference to the distribution behaviour of the pure substance, although such information acts as a useful guide. Naturally, hydrated ions tend to extract into solvents which are capable of replacing the molecules of water of hydration in the solute aggregates by their own molecules. This exchange process results in diminished ionisation of the solute, and the formation of less hydrophylic solvated groups, with the result that these tend to pass through the interface into the organic phase. The properties of solvents can often be modified by the inclusion of a suitable solute, such as an organic compound which forms an uncharged chelate compound of the material to be extracted. By such devices it is possible to extract practically every metal, except possibly some of the alkali metals.

Having chosen the solvent, one must consider the selectivity of the system, i.e., the differences in partition ratios between solutes of interest. The ratio of the partition ratios of the two solutes involved (β) is a customary measure of expressing selectivity. Where this selectivity is not as high as one would wish, a retrograde extraction procedure can be used, i.e. back-extracting the undesired solute into an aqueous phase. Alternatively, the organic phase may be purified by equilibrating it with an aqueous phase containing an agent which is capable of forming a tightly bound complex with the unwanted solute whilst not reacting with the other. It may of course be preferable to add the complexing agent to the original aqueous solution, but frequently other ions present in the latter enter into competition for it. The surface activity of the solutes, and the tendency for emulsions to form, play important roles in assessing the practicability of the procedure. It is not always feasible to suppress emulsification by the addition of other agents, since the increase in the ionic strength of the solution usually has an adverse effect on the percentage extraction. The relative densities of the

organic and aqueous phases must also be taken into consideration, for this has a profound effect on the speed of operation. Trouble from this source most frequently arises where a solvent less dense than water is being used. Transference of the solute to the organic phase increases the density of the latter and decreases that of the aqueous phase, with the result that the interface may become poorly defined. In many cases this fault is simply remedied by diluting the organic phase with a denser-than-water liquid, which does not interfere with the efficiency of the extracting solvent to any marked extent. The ease of recovery of the solute from the organic phase, or its determination in that phase by some method such as measurement of absorbancy, conductivity, radioactivity, specific gravity, viscosity, etc., is important where the substance is to be determined, or the recovery of the solvent in a pure condition for further operations must be taken into consideration. Other important points are the chemical stability of the solutes in the system, the rate of transference of the solute from the aqueous to the organic phase, the heat of solvation or transference, and the miscibility of the two phases. In several cases the heat effect is very marked, as in the extraction of ferric chloride from hydrochloric acid medium by diethyl ether, and in many instances the mutual solubility of the solvent and aqueous phase may become so considerable that not only does poor extraction occur, but the percentage recovery of the solvent becomes very low. In other cases a third phase may appear due to effects which need not be discussed here. An instance of the instability of the solute in the organic phase is the photochemical reduction of ferric chloride in ether solution. The ferrous form is insoluble and the efficiency of extraction is therefore poor under actinic conditions. The vapour pressure of the organic solvent must be allowed for when enclosed systems are being used, particularly where heating effects are observed. In this connection it should be observed, however, that it is generally preferable to use an extraction procedure at as low a temperature as possible, since elevated temperature generally results in diminished extraction. This may, perhaps, in many cases be attributed to increased ionisation of the solute in the aqueous phase.

The shape of the partition isotherm must be considered, particularly in those cases where complete extraction of the solute is required. The ideal form of the isotherm is shown as a straight line in Fig. 1, i.e., the partition ratio is independent of concentration, according to the law of Nernst. The upper curve represents that for a system where the ratio increases with solute concentration, and the lower curve portrays the behaviour of a system where the ratio decreases with increasing concentration of solute. Few solutes follow the ideal case, deviations being most marked in concentrated solution. At concentration levels of 1% or less, however, the deviation is usually negligible. It is not essential that either the partition ratio or the value of β for two solutes should be large if continuous extraction or a countercurrent distribution technique can be employed, and indeed only fairly recently a separation procedure for the rare earth elements, where the separation factor was only 1.06, has been suggested¹. However, in almost every case, inorganic extraction procedures have been dealt with by batch or single stage methods, although it is fairly obvious that much progress will be made in future years by the application of countercurrent procedures. The trend of affairs suggests that much may be expected from

liquid-liquid extraction techniques in inorganic analysis in the future. Phenomenal success has been obtained in the separation of the rare earths, and already Steinbach and Freiser² have suggested that the next logical step in solvent extraction of metals as chelates is the development of a systematic separation scheme. Several schemes of a limited nature have already been devised, e.g., that of Strafford, Wyatt and Kershaw³ dealing with arsenic, copper, lead, zinc, iron, bismuth, mercury, and cadmium.

EXTRACTION OF GROUP 1 METALS (Cu, Ag, Au)

Copper

The extraction of copper from aqueous solution, by means of an immiscible organic solvent, invariably utilises the solubility of a chelate compound, or of a salt of an organic acid, in the non-aqueous phase. The inorganic salts of copper do not appear to be markedly soluble in water-immiscible organic solvents, although compounds such as cupric chloride are readily soluble in the lower aliphatic alcohols and solvents which form co-ordination compounds with cupric salts, e.g., pyridine. An exception, however, is the extraction, by amyl alcohol and ether, of the thiocyanate complex formed on addition of ammonium thiocyanate to a cupric salt in solution.

Extraction as Dithiocyanatopyridine Cu^{II}

The precipitation of copper by means of pyridine (Py) and thiocyanate as the green complex, non-electrolyte dithiocyanato derivative $[\text{Cu}(\text{Py})_2(\text{CNS})_2]$, has been recommended by Spacu⁴⁻⁶ for the quantitative gravimetric macro- and micro-determination of copper. Several workers have extracted this compound into solvents such as chloroform in order to effect a direct colorimetric determination of copper. Moeller and Zogg⁷ have recently subjected the method to more detailed examination, and report that chloroform is a more effective solvent than bromoform, chlorobenzene, bromobenzene, carbon tetrachloride, benzene, or hexane. They also comment that an excess of pyridine or thiocyanate, beyond what is necessary for formation of the complex, has no apparent effect on the reaction, and that extraction is complete under any conditions where the reactants are present in at least stoichiometric amounts. Although no data are given, the partition coefficient would appear to be very favourable and the distribution rapid. The most concentrated solution extracted was 0.003 M in copper, but, since chloroform solutions up to 0.01 M were prepared by evaporation of the former, there would appear to be distinct possibilities of extracting more concentrated solutions. The absorption spectrum in the visible region is characterised by a maximum at 415 m μ and a minimum at 540 m μ . No interferences are mentioned, but Chalk⁸ has indicated that milligram amounts of copper may be extracted from 35 ml. volumes containing 50 mg. amounts of iron: he obtained complete extraction in 15 seconds. Ferrous and mercurous ions interfere and must be oxidised, and nickel, cobalt, and silver must be absent, but moderate amounts of metals such as aluminium, antimony, bismuth, cadmium, chromium, manganese, zinc, titanium, and uranium may be tolerated.

Extraction as Copper Butyrate

Wet, Lyons and Carlton⁹ have shown recently that copper may be isolated from other metals by extraction

as the salt of butyric acid. When solutions of copper ions are treated with hydroxide or carbonate and adjusted to the proper pH value, the addition of an aliphatic acid results in the formation of the copper salt of the acid, which may then be extracted into an organic solvent, thus offering a neat means of isolating copper. The authors found that the maximum efficiency of extraction was obtained with a benzene-butyric acid system, but they recommend that a 5% capric acid in ethyl acetate reagent be used instead, because of the obnoxious odour of the superior reagent. Complete removal of copper from aqueous solutions between pH 6.3 and 10.3 occurred, with manganese, iron, nickel, lead, cobalt, and ruthenium constituting the positive interferences. The butyric acid-benzene system extracted only manganese and iron with the copper. It is of interest to note that although none of the solvent systems examined removed ruthenium from pure solution, it was always co-extracted by the copper. With the capric acid-ethyl acetate system, trivalent chromium, rhodium and ferrocyanide prevented extraction of copper. In the absence of these, complete removal of copper was obtained from 0.01 M solutions, using an equal volume of the reagent. The colour of the copper in the organic layer was so intense that the possibility of applying an absorptiometric finish was suggested.

Extraction with Acetyl Acetone

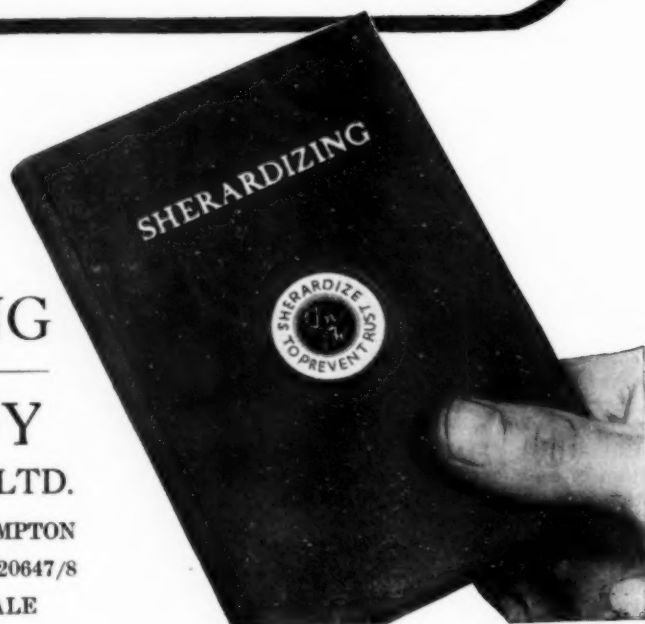
Steinbach and Freiser² have recently made an examination of acetyl acetone as an extracting agent and solvent, as this substance forms over sixty metal chelates. Generally, the solubility of the acetyl acetates in organic solvents is of a much higher order than that of most other metal chelates, i.e., of the order of grams rather than milligrams per litre. Since the solubility of a substance is normally greatest in a solvent having a similar molecular structure, Steinbach and Freiser used the acetyl acetone itself as solvent. The aqueous phase is constantly saturated with the solvent and, therefore, the reagent concentration in the aqueous phase remains constant during the extraction, regardless of the amount of metal to be extracted. In the organic phase, the high reagent concentration makes possible the extraction of metals from more acidic solutions than has hitherto been possible. This suggests that the extraction of several metals which hydrolyse rather easily may be possible using this type of technique.

A complete separation of copper and zinc was obtained on a sample of macro-proportions, containing 0.1 g. each of copper and zinc, by means of both batch and continuous extraction procedures using acetyl acetone. In the first method 200 ml. of aqueous solution containing 0.13 g. of zinc and 0.09 g. of copper were stirred magnetically with 50 ml. lots of acetyl acetone after adjustment of the pH to 2.1 with sulphuric acid. After five minutes stirring the layers were allowed to settle and the acetyl acetone phase siphoned off. Five extractions left no visual sign of copper remaining in the aqueous phase, and seven operations gave complete removal of copper without any loss of zinc. In the continuous extraction method, 300 ml. of solution containing similar amounts of the ions at pH 2.4 were treated with acetyl acetone in a continuous extractor for 4 hours. At the end of two hours no visible signs of copper remained in the aqueous phase. All the copper save 40 $\mu\text{g.}$ was removed from the aqueous phase without measurable loss of zinc.

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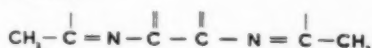
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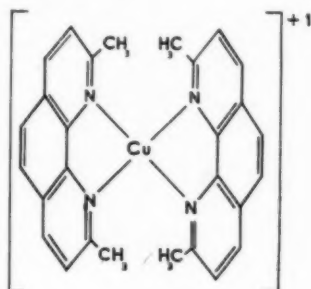
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Extraction with 2, 9-Dimethyl-1,10-Phenanthroline (Neocuproine)

2,2'-Diquinoline was described by Breckenridge, Lewis and Quick¹⁰ and given the name Cuproine by Hoste¹¹, who studied several other 2,2' dipyridine derivatives because of the marked chelating powers of these substances for cuprous copper. Hoste designated the functional group



present in some of these molecules as copper specific but, owing to preparative difficulties, diquinoline was accepted as the most feasible reagent. Smith and McCurdy¹² used 2,9-dimethyl-1,10-phenanthroline as a reagent containing Hoste's cuproine group for the spectrophotometric determination of cuprous copper. Neocuproine, as the authors named it, forms a bright orange complex with cuprous ions in acetate-buffered media over the range pH 3–10.



This complex is readily extracted by water-immiscible alcohols such as *n*-amyl alcohol, isoamyl alcohol and *n*-hexyl alcohol. No other ions were observed to form coloured complexes which were extracted under the conditions employed by the authors. Distribution coefficient measurements revealed *n*-hexyl alcohol to be the best solvent. The procedure appears to be satisfactory for the extraction of amounts of copper in the range 0.1–0.01 mg., but the authors were concerned with spectrophotometric determination and, therefore, did not stress the features of the extraction process. Whilst it is uncertain whether higher concentrations can be extracted, it is almost certain that very much more dilute solutions can be extracted, since a limit of identification of 0.03 µg. is claimed.

Extraction with Diethyldithiocarbamate, Oxine, Dithizone and Cupferron

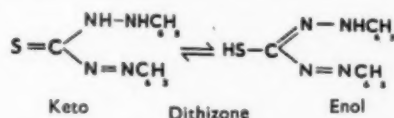
The sodium salt of diethyldithiocarbamate, $(\text{C}_2\text{H}_5)_2\text{NCS}_2\text{Na}$, may be used for the colorimetric determination of copper, since an intensely yellow-brown colour is formed in acid, neutral or ammoniacal solution. Unfortunately, the copper compound is rather insoluble in water. It is, however, appreciably soluble in water-immiscible organic solvents. Three of these have been widely used in connection with the colorimetric determination of copper, namely amyl alcohol, chloroform and carbon tetrachloride. Whilst all three solvents have been employed fairly extensively, carbon tetrachloride has been considerably more used than the others. The cations which usually accompany copper into the organic phase from an alkaline aqueous solution containing complexing agents such as citrate and pyrophosphate, are

bismuth, cobalt and nickel¹³. Strafford, Wyatt and Kershaw³ used chloroform to extract the dithiazonates of copper, bismuth, mercury and the noble metals from lead, nickel, zinc, cadmium, cobalt and arsenic in 2 *N* hydrochloric acid. Arsenic, in the trivalent state and small amounts of iron are readily extracted. Martens and Githens¹⁴ preferred to extract copper with a solution of zinc dibenzylthiocarbamate in carbon tetrachloride.

8-Hydroxyquinoline forms insoluble chelate compounds with very many metals. Many of these 'oxinates' are soluble in water immiscible organic solvents, particularly chloroform. Moeller¹⁵ has examined the chloroform extraction of several of these chelates and has reported that the removal of copper is complete from solutions in the pH range 2.7–7.0 and from ammoniacal solutions in general. By this method Moeller was able to determine copper in the presence of forty-fold amounts of zinc and cadmium by extraction at pH 4.0 and measurement of absorbancy at 410 mµ. Moeller's method involved four extractions with a 0.01 M solution of oxine. The process was subjected to re-examination by Gentry and Sherrington¹⁶ who found that a much wider pH range was obtained by using a 1% solution of oxine (i.e. 0.07 M). Working with 50–200 µg. amounts of various ions in 50 ml. of solution, they reported the extraction of copper to be complete within the pH range 2.8–14.

The solvent extraction of metal cupferrates from aqueous solutions has been thoroughly examined by Furman, Mason and Pekola¹⁷. Furman and his co-workers found that, generally speaking, extraction with cupferron was superior to precipitation for the removal of milligram or microgram amounts of those metals which form extractable compounds. For example, in the case of iron, precipitation from concentrated uranium solutions is far from complete, whilst extraction gives complete removal. Cupric cupferrate was found to be completely extracted from 10% hydrochloric acid, but incompletely from 1–12.5% sulphuric acid. Other metals extracted under similar conditions are uranium^{IV}, iron^{III}, titanium, vanadium^V, tin^{IV}, and molybdenum^{VI}.

Diphenylthiocarbazone (dithizone) reacts with much fewer cations than oxine or cupferron. It may therefore be said to be more selective than either. The compounds formed by dithizone are more readily soluble in water-immiscible solvents than in water, so that the extraction of metal dithizonates into solvents such as chloroform or carbon tetrachloride is a simple matter. The solvent generally preferred is chloroform.

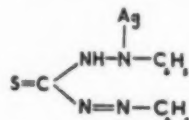


The noble metals are extracted at lower pH values than other metals; thus the extraction of silver and mercury is practically complete under conditions where the extraction of copper is negligible, i.e., below pH 2. The extraction of cupric ion is complete at pH values greater than 5–6, but, as in the case of oxinate extractions, the excess of reagent used, the presence of other electrolytes, etc., has a marked effect¹⁸.

Silver and Gold

No reports have been traced in the literature surveyed by the author, of the extraction of silver as a purely

inorganic compound, but the thiocyanate may possibly be extractable. Silver salts are known to be soluble in several non-miscible solvents¹⁹, but so far, it would appear that no system has been observed in which there is any marked preference of the silver ion for the non-aqueous medium. On the other hand, extraction of silver chelates is possible, although even here silver is not amongst the many metals which may be solvent-extracted as their oxinates or cupferrates. Extraction with dithizone may be used for the isolation of small amounts of silver in the absence of other noble metals, such as gold, palladium, etc., and mercury and copper. The silver ion reacts with dithizone, even in 0.5 N mineral acid solution, to yield a compound which dissolves



readily in chloroform, forming a yellow solution. The enol form of the reagent, present in alkaline solutions, reacts with two atoms of silver. This compound is not extractable. The formation constant of the silver dithizone compound is very high. Extraction is complete from 1 N acid and, even from 6 N sulphuric acid, 90% recovery can be obtained with microgram amounts of silver.

Gold is appreciably extracted from hydrochloric acid solutions by diethyl ether in the form of chloroauric acid^{20, 21}. Yoe and Overholser²² used this extraction to remove gold from palladium, but they preferred ethyl acetate as solvent. Iron, antimony, arsenic, and tin are appreciably extracted along with the gold, whilst lead, copper, sodium and potassium form double chlorides with gold, thus interfering with the extraction. The extraction of chloroauric acid becomes less favourable with increasing dilution. More recently, McBryde and Yoe²³ have reported that the extraction of bromoauric acid, H(AuBr₄) by isopropyl ether is more complete than that of chloroauric acid. The optimum acidity is 2.5-3 M, but the figure is not critical. Another advantage over the chloride extraction is that the falling-off in extraction in dilute solutions is not nearly so marked. Ferric bromide is extracted with the gold, but a separation may be effected by back-extraction of the gold simply by shaking with distilled water. Only a small amount of iron accompanies the gold back into the aqueous solution. Other solvents examined by McBryde and Yoe were diethyl ether, ethyl acetate and methyl isobutyl ketone.

Gold may be extracted from acid solutions by dithizone, but not by cupferron or oxine. Virtually complete extraction of gold is obtained from 8 N nitric acid at ordinary temperatures using diethyl ether. Complete extraction from an acid thiocyanate medium has also been reported. According to Kitahara, gold²¹¹ is completely extracted from hydriodic acid solution by ether.

to be continued.

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Correction

DETERMINATION OF NICKEL, CHROMIUM AND MOLYBDENUM USING THE SPEKKER ABSORPTIOMETER

THE attention of readers is drawn to the table of comparative acid costs at the top of the first column on page 52 of our last issue. These costs refer to 25 determinations and not to 250 as stated in the text. Reference is made in the table to Persulphate Tabloids. These should be Persulphate Analoids, which are supplied by Ridsdale & Co., Ltd. "Tabloids" is the registered trade name of another firm's products.

Price Peg

FIELDEN ELECTRONICS, LTD., of Wythenshawe, Manchester, manufacturers of industrial, laboratory and research electronic instruments, announce that they are freezing both home and export prices of all their products for the next six months. Mr. J. E. Fielden, Governing Director, in making this announcement, added that he hoped it would be possible, not only to maintain present prices, but to effect reductions, provided wages and costs of materials could be stabilised. Mr. Fielden expressed the hope that in the interests of the national economy, other firms would follow their lead and stabilise, if not reduce, their prices.

Fielden Electronics, Ltd., is a wholly British Company and one of the largest concerns in its particular field. Excluding America, they export over 30% of their production and are now planning an increased export drive. In America their products are manufactured and sold under licence by the Fielden Electronic Division of Robertshaw-Fulton Controls, Inc., of Pennsylvania. In Australia Fielden instruments are manufactured by their subsidiary, Fielden Electronics (Australia), Pty., of Melbourne.

Quality Control

To date, no professional body has had the responsibility for stimulating interest in the use of statistical methods of quality control. The Institution of Engineering Inspection, which has covered this field for a number of years, is therefore now taking the step of altering its Articles of Association so as to include 'quality control' as well. A new journal is also being produced by the Institution. Entitled "The Inspection Engineer incorporating Quality Control", it replaces the old-established journal "Engineering Inspection", and will pay particular attention to case studies and practical applications. The journal is to be published bi-monthly from January of this year and monthly from the beginning of 1957.

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